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FINAL REPORT

RELIABILITY, MAINTAINABILITY, STRATEGIC RELIABILITY, AND LIFE CYCLE COST COMPARISON ANALYSIS OF THREE ALTERNATIVE MK 71 MOD 0 GUN MOUNT CONTROL SYSTEM DESIGNS

July 1978

Prepared for
NAVAL ORDNANCE STATION
LOUISVILLE,KENTUCKY
under Contract N00197-76-C-0141

ARINC RESEARCH CORPORATION

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by

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ABSTRACT

This report summarizes the work conducted by ARINC Research Corporation under Contract N00197-76-C-0141, Tasks 3 and 4, for the Gun System Engineering Center/Naval Ordnance Station, Louisville, Kentucky. These contract tasks required comparisons of reliability, maintainability, strategic reliability, and life cycle costs of three alternate control systems for the 8"/55 Caliber Mk 71 Mod 0 Major Caliber Light Weight Gun (MCLWG) and a review of a preliminary development specification for a microprocessor-based control system for this gun.

SUMMARY

The Mk 71 Mod 0 Major Caliber Light Weight Gun (MCLWG) was designed and developed in the early 1960s. To date, one prototype Mk 71 Mod 0 has been manufactured and used for design verification and preproduction testing. Since this gun mount was designed, many technological advances have been made in control system design and electronic hardware. The Gun System Engineering Center (NOSL/GSEC) at the Naval Ordnance Station, Louisville, Kentucky, is evaluating the MK 71 Mod 0 Mount Control System to determine the advantages of redesigning this system before production of the Mk 71 Mod 0 Gun Mount is begun. As part of this evaluation, ARINC Research Corporation has been tasked under Contract N00197-76-C-0141 to compare the reliabilities, maintainabilities, strategic reliabilities, and costs of the existing Mk 71 Mod 0 Control System with those of two proposed alternate systems. The results of this comparison are contained in this report and are summarized below. The study focused on the electronic circuitry required for the control system alternatives that were examined.

The existing Mk 71 Mod 0 Control System, called the Option I control system in this study, is the system currently installed in the prototype gun mount. The Option II Control System discussed in this study is the existing control system with the modifications referred to in FMC Corporation Northern Ordnance Division Letter Number 0034-76-08. The third control system alternative, the Option III system, is a Standard Electronic Module (SEM) microprocessor-based system that was defined as part of this study.

The reliability estimate for each control system was based on a mission scenario that required ten hours of system operation each day over a one-year period. Under these mission conditions worst case reliabilities were predicted. In addition, a mean time between failures was calculated for each system. These results are all summarized in Table S-1.

The maintainability values shown in Table S-2 are estimates of the annual active corrective maintenance man-hours required for each system. These estimates were also based on a one-year operating period with ten hours of system operation per day.

Table S-1. MK 71 MOD 0 CONTROL SYSTEM OPTION RELIABILITY AND MTBF SUMMARY

Reliability Elements	Option I	Option II	Option III
Annual Operating Reliability at 10 hours daily operation	0.010	0.011	0.376
MTBF (Operating Hours)	790	809	3731

Table S-2. MK 71 MOD 0 CONTROL SYSTEM OPTION ANNUAL PROJECTED CORRECTIVE MAINTENANCE REQUIREMENT SUMMARY

Maintenance Elements	Option I	Option II	Option III
Expected Failures	5	5	1
Organizational Man-Hours	5	5	0.5
Depot Man-Hours	20	20	0.0
Total Man-Hours	25	25	0.5

The strategic reliability portion of this study required the use of a system model developed in Revision A of Technical Report C-1015-8 of the Fleet Analysis Center, Corona, California. In addition to the mission scenario used in developing this model, six other scenarios were defined and used in this comparison. In all scenarios, the gun mount with the Option III control system showed the highest strategic reliability. For all but the most extreme scenario conditions, strategic reliability was shown to maximize at about a two-day preventive maintenance interval. Table S-3 summarizes the maximum and two-day preventive-maintenance-interval strategic reliabilities calculated for each scenario for a gun mount containing control system Option III.

Calculations of the costs for the three control system options presumed a ten-year system life for each system produced with each system operated for ten hours a day. Cost elements examined for this study were taken from the January 1977 Life Cycle Cost Guide for Equipment Analysis, which defines a Naval Material Command life cycle cost model. In calculating system costs for this study only those elements that showed different costs among the three control system options were used. On the basis of the ten-year system costs calculated for each control system option, ARINC Research determined that Option I is least costly if twenty-one or fewer systems are to be produced, and for a total production run of more than

Table S-3. OPTION III CONTROL SYSTEM STRATEGIC RELIABILITY SUMMARY					
Mission		Optimum Maintenance Interval (Days)	Strategic Reliability		
Rate of Fire (Rounds/Hour)	Duration (Hours)		Two-Day Interval	Optimum Interval	Percent Increase For Optimum
750*	0.1	2	0.8935	0.8935	--
600*	0.5	1	0.3854	0.4453	16
1	10	7	0.9464	0.9816	4
6	10	3	0.9049	0.9094	0.5
25	20	7	0.1325	0.1396	5
100	1	2	0.8457	0.8457	--
10	20	2	0.5856	0.5856	--

*Rates extrapolated beyond current Mk 71 Mod 0 capabilities.

twenty-two systems, Option III is lowest in cost. The Option II system is more costly than Option I for twenty-one or fewer systems, and more costly than both Options I and III for twenty-two or more systems.

The comparative analyses done in this study led to the conclusion that a SEM microprocessor control system for the Mk 71 Mod 0 would provide significant reliability, maintainability, and strategic reliability advantages over the existing gun mount control system, even if it is modernized. Also, we concluded that the costs for development of a microprocessor-based control system for the Mk 71 Mod 0 Gun Mount would be recovered if more than twenty-two mounts were produced with such a control system.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Mk 71 Mod 0 8"/55 Major Caliber Light Weight Gun (MCLWG) is the product of a design and development process that began under Technical Development Plan (TDP) U-12-10 in April 1965. An explicit Mk 71 Mod 0 system designation and description were issued by the Chief of Naval Operations (CNO) through SOR12-10R1 in October 1969. To date one prototype Mk 71 Mod 0 Gun Mount has been manufactured and has completed Technical Evaluation (TECHEVAL) and Operational Evaluation (OPEVAL). The Naval Sea Systems Command (NAVSEA) is currently participating with DoD in a Mk 71 Mod 0 DSARC III level system review that is expected to result in a production authorization for the Mk 71 Mod 0 Program.

The electronic control subsystem of the prototype Mk 71 Mod 0 Mount was designed in the early 1960s. Since that time, progress made in the electronics industry and in electronic control system design has made it possible to produce systems of the type needed to control the Mk 71 Mod 0 that are cheaper, more reliable, easier to maintain, and generally more capable and flexible than the system used to control the prototype gun mount. SEATASK No. 653-025-066-1, Subtask 15.C.2.6, directed the Gun System Engineering Center of the Naval Ordnance Station, Louisville, Kentucky, (GSEC/NOSL) to analyze the prototype control system and recommend changes to the production version of the Mk 71 Mod 0 Gun Mount. The results of that analysis are presented in GSEC/NOSL Report R228 of 9 April 1976.

GSEC Report R228 outlines two approaches for modernizing the Mk 71 Mod 0 Control System. One considers making changes to the existing design and lists changes needed to bring the system up to present performance requirements. The other approach discussed in R228 conceptually defines a new microprocessor-based control system design. In the R228 analysis, GSEC reviewed fundamental aspects of control system cost, reliability, maintainability, and human engineering. These analyses resulted in a preliminary recommendation to redesign the Mk 71 Mod 0 Control System as a microprocessor-based system using Standard Electronic Modules (SEMs).

To supplement the analysis described in R228, GSEC/NOSL tasked ARINC Research Corporation to compare the reliability, maintainability, strategic reliability, and life cycle costs of the existing control system and the

two alternatives to provide more data for selection of a production version control system. The requirements for conducting this comparison are defined in Contract N00197-76-C-0141.

1.2 STUDY SCOPE

Under Contract N00197-76-C-0141, the following two tasks relating to the Mk 71 Mod 0 Control System are assigned:

- Conduct a specific reliability, maintainability, strategic reliability, and life cycle cost comparison among the control system options
- Review a preliminary system development specification for a microprocessor-based Mk 71 Mod 0 Control System

The emphasis in both these tasks was toward quantified analysis of the electronic circuitry involved in the three system options. The physical, mechanical, and human engineering aspects of the control panels for each design option have been addressed in detail by other GSEC studies.

The main body of this report addresses the effort and results of the comparison. Chapter Two outlines our technical approach to this task. Chapter Three provides the data and results of the reliability portion of this study; Chapter Four addresses the maintainability data and analysis portion of the study, Chapter Five discusses the strategic reliability analysis portion; and Chapter Six gives the data and results of the control system life cycle cost analysis. Chapter Seven summarizes the overall conclusions and recommendations developed.

Appendix A provides the results of the review of the preliminary development specification for a microprocessor-based Mk 71 Mod 0 Control System, Control Console EX___ Mod 0. Appendixes B, C, and D provide supplemental information for discussions in the body of this report.

CHAPTER TWO

TECHNICAL APPROACH

2.1 GENERAL

The first requirement in this study was to define a functionally consistent hardware group under each control system option. The identified hardware in each option formed the basis for quantification of the reliability, maintainability, and cost data. To the extent possible, the data were extracted from existing documentation. Substantial data collection and definition were required only for the microprocessor-based control system.

A method for estimating each of the systems' reliabilities, maintainabilities, strategic reliabilities, and life cycle costs was established in the form of a system model. These models were then exercised using the identified system data and the operational and maintenance scenarios defined in Contract N00179-76-C-0141. In the strategic reliability analysis, additional scenarios were created and used in an effort to better understand and compare this important characteristic of each system option.

2.2 CONTROL SYSTEM DEFINITIONS

The Mk 71 Mod 0 control functions that were considered to be included in the systems defined for this study are:

- Train and elevation control logic
- Loading and firing control logic
- Logic circuit test and fault isolation
- Train and elevation test
- Loading and firing simulation
- Power supply functions for all above functions

Specifically, this study focuses on the electronic circuitry that performs these control functions. The mechanical, structural, and operator interface and display portions of the control systems are not included in this study. While those portions of the optional control systems will differ, they are not expected to differ sufficiently in reliability, maintainability, or cost to affect the results of this analysis.

Data used in this study refer only to the several functions listed above. Also, because this is a comparative study, data were determined for the three control systems only when the factor under consideration could be expected to differ in value among these systems. If a factor was expected to have the same value for all three systems, the factor was not considered in this study and no data for the factor were sought. All system level numbers developed in this report are relative; they should not be taken as total system values, especially in the case of the cost elements.

2.2.1 Existing Mk 71 Mod 0 Control System (Option I)

For this study, the existing Mk 71 Mod 0 Control System was considered to include the electronic circuitry in the EP2 Panel (Mk 295 Mod 0), the EP3 Panel (Mk 293 Mod 0), Power Supplies PSZ2 and PSZ4 in the EP1 Panel (Mk 294 Mod 0), and the Order Signal Generator (Mk 10 Mod 0). The specific circuits that were included are identified in Table 2-1.

Table 2-1. OPTION I CONTROL SYSTEM CIRCUITS

Schematic Diagram	Card Type	Quantity per System
2862467	Inverter/Buffer	8
2625642	Buffer	11
2625643	Logic	72
2625644	Light Driver	8
2625645	Output Drivers	9
2625646	Relays, Latching	4
2625647	Relays	3
2625648	Auxiliary Circuits	2
2625601-2 Type	Power Supply	2
2862468	Timing Circuit	1
2635853	Output Drivers, AC	3

The system containing the items specified in this section will hereafter be referred to as the Option I control system.

2.2.2 Modified Existing Mk 71 Mod 0 Control System (Option II)

The modified existing Mk 71 Mod 0 Control System was considered to be all the circuitry listed in Table 2-1, except as altered according to the information listed in FMC Corporation/Northern Ordnance Division Letter

Number 0034-76-08, dated 20 May 1976. That letter describes changes that are necessary to improve Mk 71 Mod 0 Gun Mount operation to a level consistent with current operating requirements. Changes described in that letter address many aspects of mount hardware, some of which affect only mount components outside the system considered in this study. The change items described in that letter that apply to the defined Mk 71 Mod 0 control system are listed in Table 2-2 along with brief descriptions.

Table 2-2. PROTOTYPE CONTROL SYSTEM CHANGES FOR SYSTEM OPTION II FROM FMC/NOD LETTER 0034-76-08

Item Number	Brief Description
3	Design, build, and install a round counter circuit interlock
8	Include cell select feature as a mount operator control option
10	Include EP3 Panel function in EP2 Panel
11	Replace pin contacts with wire-wrap contacts
12	Eliminate mechanical time delay relays
14	Redesign cycle timer
17	Add audio alert to EP2 Panel
19	Add troubleshooting readout keyboard

These changes are expected to be accomplished by wiring and hardware changes within the circuitry of the existing control system. The other items listed in the FMC/NOD letter are considered not to have any effect on this study.

The system containing the items specified in this section will be referred to as the Option II control system.

2.2.3 Microprocessor-Based Control System (Option III)

At the time of this study no documentation existed (formal or informal) that described or specified the hardware or structure of a microprocessor-based control system for the Mk 71 Mod 0 Control System. All previous considerations of this type system have been conceptual. Therefore, in order that a hardware system could be postulated for this study, ARINC Research, the Gun System Engineering Center/NOSL, and the Naval Avionics Center/Indianapolis defined fundamental requirements for such a system. These requirements led to the definition of a triple microprocessor control system to be constructed using Standard Electronic Modules (SEMs).

Each of the three processors would utilize an INTEL 808A microprocessor (SEM Module Code HRH) and have its own independent 8K work memory.

One processor would be dedicated to train and elevation control functions and the other two would operate in parallel to provide redundant cross-checking loading and firing control. The train and elevation processor would be designed to run a self-test routine periodically and halt mount activity whenever it detected any failure. The loading system processor outputs would be continually compared with one another through a hardwired comparator. Whenever any output signal discrepancy occurred between the loading and firing processors, processing would automatically halt and each processor would test itself. The results would be displayed to the operator who could then shut down, restart, continue, or operate the mount with only one loading and firing system processor. In addition to having extensive self test capabilities, each processor would be designed and programmed to test the other two processors in the system.

Figures 2-1 and 2-2 give fundamental, system-level functional diagrams for the processors selected for this study. The SEMs required to implement this system are listed in Table 2-3.

The system containing the items specified in this section will be referred to as the Option III control system for this study.

2.3 STUDY MODELS

2.3.1 Reliability Model

The optional control systems under study for the Mk 71 Mod 0 Gun Mount are relatively complex systems that operate in many modes under widely varying mission requirements. Estimating the field reliabilities of these systems would require extensive analysis to determine system performance under all failure conditions. Because such analysis is beyond the scope of this study, the reliabilities used for this comparison are worst-case system reliabilities that imply that each system is deemed to fail whenever any component in it fails.

To determine worst-case reliabilities for this study, each system was visualized as a series arrangement of blocks, with one block representing each circuit board in the system. The failure rate for such a series system is simply the sum of failure rates for the individual blocks that are part of the system. Therefore, each system reliability for this study was calculated using the following equation:

$$R = e^{-\lambda t}$$

where:

- R = System reliability
- e = Base of the natural logarithms
- t = System operating time for the interval over which reliability is to be calculated (hours)
- λ = System failure rate = sum of system component failure rates (failures per hour)

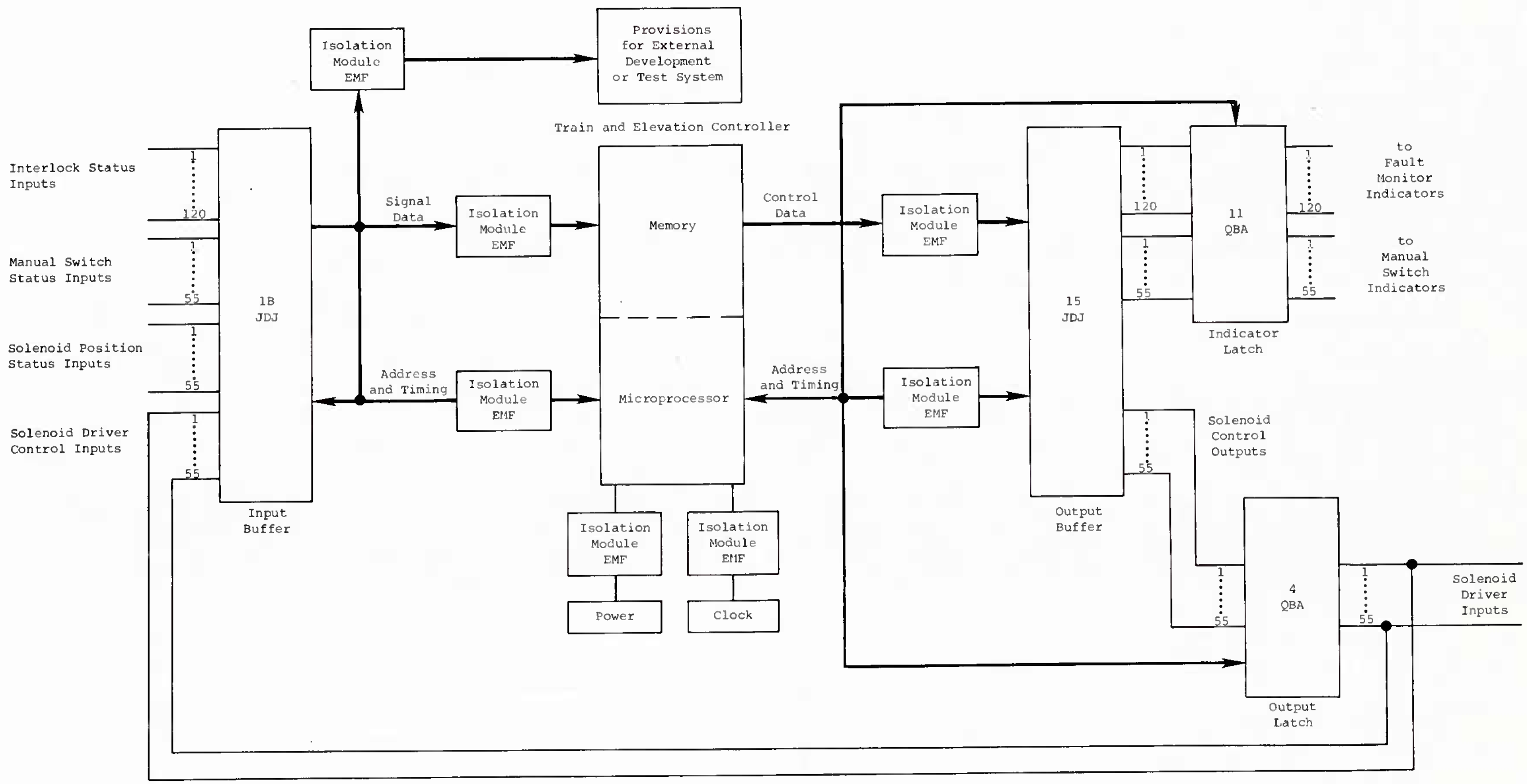


Figure 2-1. TRAIN AND ELEVATION PROCESSOR FUNCTIONAL DIAGRAM

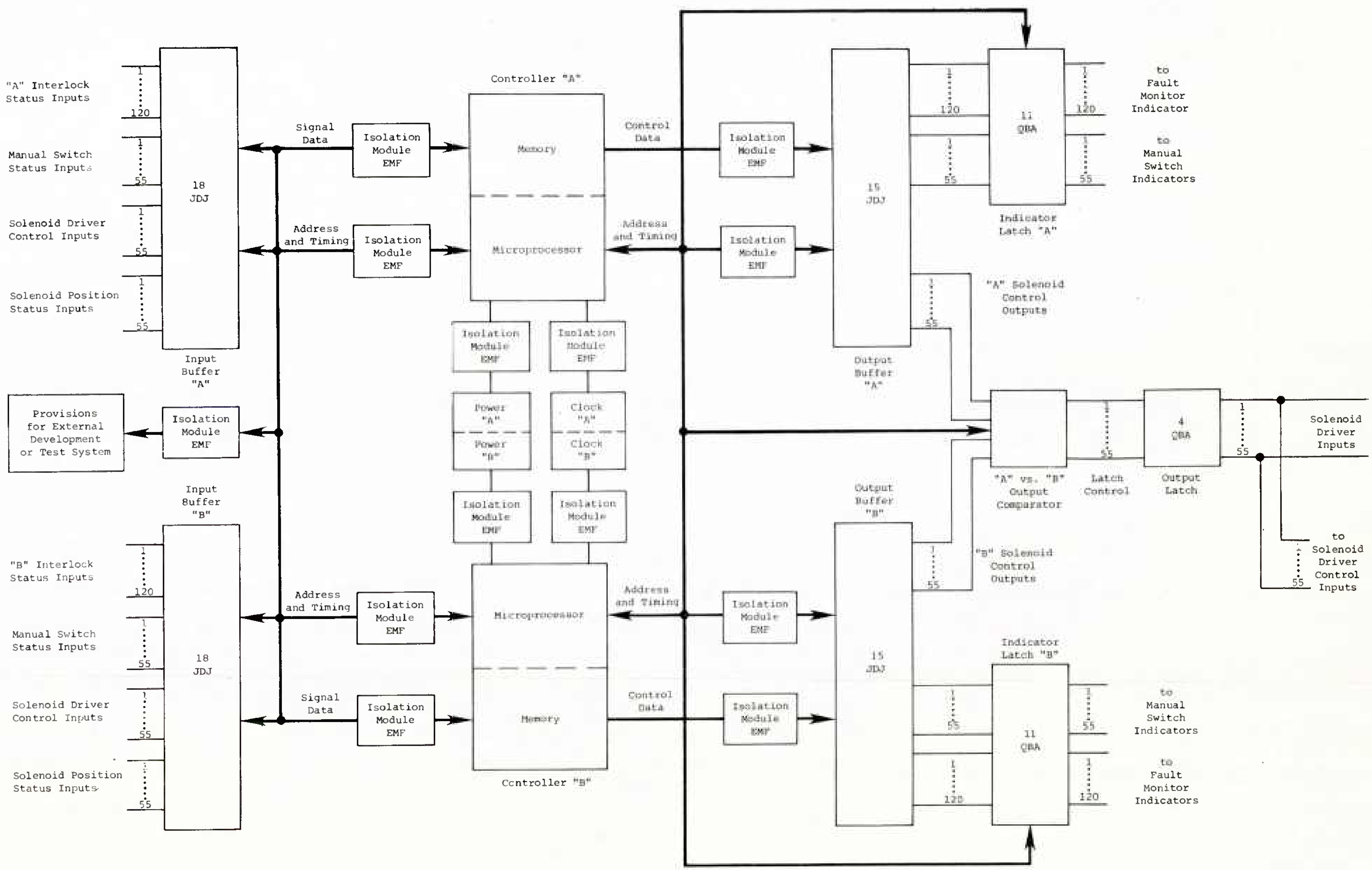


Figure 2-2. LOADING AND FIRING CONTROL PROCESSOR FUNCTIONAL DIAGRAM

Table 2-3. OPTION III CONTROL SYSTEM STANDARD ELECTRONIC MODULES		
Module Type	Description	Quantity per System
BYF	1024 X 1-Bit RAM	3
CMH	Test Point Module	6
EHR	Transceiver Timer	3
EMF	Isolation Module	18
GDJ	4 Four-Bit Latches	3
GPP	5 Volt, 10 Amp Power Supply	3
GQB	Bus Driver	3
GVQ	Oscillator	3
GYC	2 256 X 8-Bit PROM	90
HRH	8080A µP Module	3
HRK	Switch Debounce Module	5
JDJ	4 Four-Bit Series/Parallel Shift Register	99
JRH	Clock Driver and Power Reset Module	3
LDC	Eighteen Inverter Gates	6
LDQ	12 Two-Input NAND Gates	9
QBA	4 Four-Bit Latches (Flip Flop)	37
UMU	LED Display	5
SPECIAL 1	16-Bit Input/8-Bit Output Comparator Module	7

2.3.2 Maintainability Model

Each of the three control system options is to be maintained at the organizational maintenance level by circuit card removal and replacement, with the removed circuit cards from system Options I and II being returned to the depot for repair. All circuit cards in Option III are non-repairable, throwaway modules. The maintainability of systems such as these with line-replaceable, plug-in modules, is a function of the effort required at the organizational level to identify, remove, and replace faulty circuit cards,

and the effort required to repair circuit cards at the depot. Therefore, an estimate of the system corrective maintenance man-hours per year will be used as a measure of system maintainability for this study. The equation used to calculate this maintenance effort is:

$$M_i = (\lambda_i \times H_o) \times (\overline{M}_o + \overline{M}_D)$$

where

M = System corrective maintenance man-hours per year for Option i

λ_i = Worst case system failure rate for Option i (failures/hour)

H_o = Total annual system operating hours (hours/year)

$\overline{M}_o$ = Mean organizational level active maintenance man-hours per failure

$\overline{M}_D$ = Mean depot level active maintenance man-hours per failure

2.3.3 Strategic Reliability Model

The strategic reliability of the Mk 71 8"/55 MCLWG is the joint probability that the gun will be ready when needed and reliable throughout a specified mission. This strategic reliability can be evaluated through the use of an existing model, which is described in Fleet Analysis Center/Corona, California, Technical Report Number C-1015-8, Revision A, dated 28 February 1977.

The model assumes that the weapon is composed of two systems -- the control system and the loading and firing system. Equations were derived in Report C-1015-8 to estimate the reliability and availability of these systems. The strategic reliability for each system is defined as the product of the system reliability and availability; the gun strategic reliability is defined as the product of the strategic reliabilities for both systems. The resulting equations from the model are given below:

$$SR(t,\phi) = A_c \times D_c(t) \times A_s \times D_f(t,\phi)$$

$$A_c = \frac{\Theta_c}{\Theta_c + \overline{M}_c}$$

$$D_c(t) = e^{-t/\Theta_c}$$

$$A_s = \frac{2\Theta_s\left[\phi\left(\sqrt{\frac{\pi}{2}}\,\frac{\phi_s}{\Theta_s}\right) - \frac{1}{2}\right]}{2\Theta_s\left[\phi\left(\sqrt{\frac{\pi}{2}}\,\frac{\phi_s}{\Theta_s}\right) - \frac{1}{2}\right] + \overline{M}_P + \left(\overline{M}-\overline{M}_P\right)\cdot\left(1-e^{-\pi\phi^2_s/4\Theta^2_s}\right)}$$

$$D_f(t,\phi_f) = \frac{\phi\left(\sqrt{\frac{\pi}{2}}\ \frac{\phi_f+t}{\Theta_f}\right) - \phi\left(\sqrt{\frac{\pi}{2}}\ \frac{t}{\Theta_f}\right)}{\phi\left(\sqrt{\frac{\pi}{2}}\ \frac{\phi_f}{\Theta_f}\right) - \frac{1}{2}}$$

where:

$SR(t,\phi)$ = Gun mount strategic reliability for a daily mission of duration t hours with successive preventive maintenance intervals of ϕ hours.

A_c = Steadystate availability of gun control system

A_s = Steadystate availability of gun loading and firing system

$D_c(t)$ = Reliability of gun control system for a mission of duration t beginning at random

$D_f(t,\phi_f)$ = Reliability of gun loading and firing for a mission of duration t beginning at random, given preventive maintenance interval ϕ_f

e = Base of natural logarithms

ϕ,ϕ_f,ϕ_s = Interval between successive preventive maintenance events measured in calendar time, firing time, and standby time, respectively

$\overline{M}_c,\overline{M}$ = MTTR of gun control system and gun loading and firing system, respectively

$\overline{M}_p$ = Mean preventive maintenance downtime

t,τ = Firing time and standby time, respectively

$\Theta_c,\Theta_f,\Theta_s$ = MTBF of gun control system, gun loading and firing system in firing operations, and gun loading and firing system in standby operations, respectively

2.3.4 Cost Model

The cost comparison of the three Mk 71 Mod 0 Control System options required:

- Identifying the appropriate cost parameters
- Estimating the cost parameter values
- Calculating the cost for each option

A primary concern of this study was the determination of cost changes associated with the increased capabilities of Options II and III over Option I. Consequently, the cost elements of interest were only those that changed when using Options II and III in lieu of Option I. Therefore, costs needed to be analyzed in detail only for those cost elements that were found to change for these options. The system life cycle cost model defined in the January 1977 Life Cycle Cost Guide for Equipment Analysis developed for the Naval Material Command was used as the basis for this portion of this study.

The individual cost elements that make up total system life cycle cost as defined by the Life Cycle Cost Guide are identified in Table 2-4. This table also identifies the applicability of each of these cost elements to this study. The degree of change between the Option I costs and the Option II and III costs is indicated. Wherever significant changes were indicated, explicit cost data were developed for each control system. Those elements shown to have insignificant cost changes for Options II and III were assumed to have equal value in all options. The elements in Table 2-4 shown to have significant cost differences are summed to determine a value for each system life cycle cost. System validation studies for Options I and II have been accomplished, and specific validation requirements may not be imposed on the Option III system in order to minimize the research and development effort for this option. Therefore, for the purposes of this study validation activities have been assumed completed for all three control system options.

For this study each cost factor was defined in terms of recurring and non-recurring costs in order to establish how each factor varies with the number of systems purchased. A learning curve factor was applied to manufacturer hardware costs identified in this model. The fundamental cost equations used to calculate the cost elements from Table 2-4 are given in Appendix B. Only those model equations that were required in this study are included.

Table 2-4. LIFE CYCLE COST ELEMENT DIRECTORY			
Life Cycle Cost Elements	Phase Completed	Insignificant Change	Significant Change
Research and Development			
Validation			
Contractor	I, II, III*		
Government	I, II, III		
Full Scale Development			
Contractor			
Management			II, III
Engineering			II, III
Prototype Hardware			II, III
Software		II	III
Test and Evaluation		II	III
Documentation			II, III
Support and Test Equipment		II	III
Government			
Program Management			II, III
Prototype Test and Evaluation			
Training		II, III	
Test Site Activation		II, III	
Test and Evaluation			II, III
Production (Investment)			
Government Program Management		II, III	
Prime Equipment Acquisition			
Production Hardware			II, III
Production Support and Services		II, III	
Production Test and Evaluation		II, III	
Transportation		II, III	
Installation and Checkout		II, III	
Initial Support Acquisition			
Support and Test Equipment Acquisition		II	III
Supply Support			
Initial Spares			
Prime Equipment			II, III
Support and Test Equipment		II, III	
NSN Entry into the Supply System		II	III
Facilities			
Operational		II, III	
Maintenance		II, III	
Documentation			
Acquisition		II, III	
Reproduction and Distribution		II, III	
Training			
Operator		II, III	
O/I Level Maintenance		II, III	
Depot Level Maintenance		II, III	
Instructor		II, III	
Training Aids		II, III	

*Roman numerals indicate control system option.

(continued)

Table 2-4. (continued)

Life Cycle Cost Elements	Phase Completed	Insignificant Change	Significant Change
Operating and Support			
Operation			
Personnel		II, III	
Facilities		II, III	
Energy Consumption		II, III	
Material Consumption		II, III	
Software Maintenance		II	III
Support			
Corrective Maintenance			
Labor			
O/I Level (Remove and Replace)		II	III
O/I Level (Repair)	N/A	N/A	N/A
Depot Level (Repair)		II	III
Repair Material		II	III
Transportation and Packaging			
Material Handling Labor		II, III	
Packaging Material		II, III	
Shipping		II, III	
Preventive Maintenance			
Labor		II, III	
Material		II, III	
Overhaul			
Labor		II, III	
Material		II, III	
Transportation		II, III	
Support and Test Equipment Maintenance		II, III	
Facilities			
Shop Space			
O/I Level		II, III	
Depot Level		II, III	
Inventory Storage			
O/I Level		II, III	
Depot Level		II, III	
Documentation Maintenance		II, III	
Supply Support			
Replenishment Spares		II	III
Supply System Management		II	III
Training			
Operator		II, III	
O/I Level Maintenance		II, III	
Depot Level Maintenance		II, III	
Termination	N/A	N/A	N/A

CHAPTER THREE

RELIABILITY ANALYSIS

3.1 DATA FOR ANALYSIS

3.1.1 Option I Failure Rate Data

Control system circuit cards in the Mk 71 and Mk 45 gun mounts are essentially the same in design and function, and they are both produced by the same manufacturer. The failure rates for circuit cards used in the Option I control system for the Mk 71 Mod 0 Gun Mount were taken from ARINC Research Corporation's final report, *Reliability Prediction for the Electrical and Electronic Control Circuitry of the Mark 45 Mod 0 Gun Mount,* Publication 978-02-2-1168, dated March 1972. Predicted failure rates for these cards were calculated in that report, and those rates cited for use reflect typical design stresses on components and an ambient operating temperature of 75°F. The wiring interconnection failure rate was taken from MIL-HDBK-217B for hand soldered connections. Table 3-1 gives the resulting rates used for the Option I control system.

3.1.2 Option II Failure Rate Data

It is expected that the circuitry required to implement the Option II control system can use the same type of electronic circuit components used in the Option I system. Therefore, the failure rate data for the circuit cards of the Option II Mk 71 Mod 0 Control System should be identical to those of the Option I system. No information gathered or generated in this study suggests that any control system circuit card reliability should improve or be degraded between the Option I and Option II versions of the Mk 71 Mod 0 Gun Mount Control Systems. The only definable difference in failure rates between Option I and Option II result from a difference in their wire connection schemes. Option I's hand soldered connections have a failure rate of 28.78 failures per million hours, while the wire wrap backplate of Option II, with the same number of interconnections, has a total estimated failure rate of 0.027 per million hours. This gives Option II an estimated overall failure rate of only 1236 failures per million hours, slightly lower than Option I's estimated 1265 failures per million hours.

3.1.3 Option III Failure Rate Data

The Option III control system is made up of standard electronic modules. The reliability characteristics of these modules are carefully tested and

Table 3-1. OPTION I CONTROL SYSTEM CIRCUIT CARD FAILURE RATES		
FMC Card Type	Quantity per System	Failure Rate per Million Hours
Circuit Card Interconnections	7380*	0.0039
2862467 - Inverter/Buffer	8	62.0
2625642 - Buffer	11	18.8
2625643 - Logic	72	0.3
2625644 - Light Driver	8	5.8
2625645 - Output Drivers	9	25.1
2625646 - Relays, Latching	4	26.1
2625647 - Relays	3	26.1
2625648 - Auxiliary Circuits (007)	2	5.8
2625601-2 - Power Supply	2	7.25
2635853 - Output Driver, ac (008)	3	9.6
2862468 - Timing Circuit (011)	1	1.8
System Total		1265
*Not included in system totals.		

assured by the Standard Electronic Module Program. Table 3-2 gives a list of the modules in the Option III system and shows the failure rates for these modules that are published in MIL-M-28787 or that were provided for this study by the SEM engineering codes of Naval Avionic Center/Indianapolis. Ninety percent of the system failure rate shown in Table 3-2, 242 failures per million hours, is taken as a worst case combat critical failure rate for the strategic reliability analysis in Chapter Five.

3.2 RELIABILITY ANALYSIS

For this analysis the reliabilities of control systems Option I and III were predicted for a one-year period during which the system was to operate for ten hours each day. This required system reliability calculations for 3,650 operating hours using the model described in Section 2.3.1. The EP3 panel and order signal generator reliabilities were not included in this calculation because their annual operating times are considered insignificant compared to control system operating time and a failure (of either or both) of these test-related portions of the system would not result in failure of the control system. Table 3-3 gives the system reliability calculated for each control system option and also gives an MTBF for each system. This table shows that the probability that

Table 3-2. OPTION III CONTROL SYSTEM SEM MODULE FAILURE RATES

Module Type	Quantity per System	Module Failure Rate per Million Hours
BYF	3	8.30
CMH	6	0.45
EHR	3	1.00
EMF	18	0.23
GDJ	3	1.80
GPP	3	9.3
GQB	3	0.108
GVQ	3	0.28
GYC	90	1.0
HRH	3	4.0
HRK	5	2.00
JDJ	99	0.33
JRH	3	4.00
LDC	6	0.18
LDQ	9	0.45
QBA	37	0.50
UMU	5	1.3
Special 1	7	1.1
System Total		268

Table 3-3. MK 71 MOD 0 CONTROL SYSTEM RELIABILITY SUMMARY FOR COMPARISON

Reliability Elements	Option I	Option II	Option III
Annual Operating Reliability at 10 hours daily operation	0.010	0.011	0.376
MTBF (Operating Hours)	790	809	3731

Options I or II will survive a year of operation without failure is very low (0.01), while Option III can be expected to operate failure-free over the same period with the much higher expected probability of 0.376. This table also shows the MTBF for Option III to be four times the MTBF for Options I or II.

3.3 RELIABILITY ANALYSIS CONCLUSIONS

The analysis results from Section 3.2 show that the Option III control system will be substantially more reliable than either the Option I or Option II versions of the system. In addition to Option III's higher calculated reliability, it will have more capability than Options I or II at that reliability. The functions of the EP3 Panel and Order Signal Generator are considered to be part of the capabilities in the processors used for the Option III System. No additional equipment will be required for the Option III system to perform these functions.

CHAPTER FOUR

MAINTAINABILITY ANALYSIS

4.1 DATA FOR ANALYSIS

The data for this maintainability analysis were substantially the same as for the reliability analysis presented in Chapter Three. The mean maintenance time for each circuit card failure identification, removal, and replacement at the organizational level for Options I and II is one man-hour and the average circuit card repair at the depot takes four man-hours. The mean failure identification, removal, and replacement time for Option III is one-half man-hour and there is no required depot maintenance. This maintenance time information was provided by the engineering codes at NOSL.

4.2 MAINTAINABILITY ANALYSIS

Table 4-1 summarizes the annual maintenance man-hour requirements for each of the three control system options. They were calculated using the model described in Section 2.3.2 and are based on ten system operating hours per day for one year. The table shows that the maintenance requirements expected for Option III are far less than for the other two options. It should be noted that even with a substantially greater mean organizational level maintenance time than the half-hour specified for Option III, this system's projected maintenance burden would still be substantially less than that for Options I or II due to the higher inherent reliability of SEMs over existing control system circuit cards. Also, with the automatic fault isolation capabilities to be available with the

Table 4-1. ANNUAL PROJECTED MAINTENANCE REQUIREMENT SUMMARY (PER SYSTEM)

Maintenance Elements	Option I	Option II	Option III
Expected Failures	5	5	1
Organizational Man-Hours	5	5	0.5
Depot Man-Hours	20	20	0.0
Total Man-Hours	25	25	0.5

Option III system, some reduction in the average isolation time for non-control system failures may be possible because the flexibility of this system will be used to prompt and monitor gun mount operations and thereby help isolate mechanical and hydraulic failures.

4.3 MAINTAINABILITY ANALYSIS CONCLUSIONS

From the analysis of Section 4.2, it is concluded that the Option III control system will require significantly less maintenance than either the Option I or Option II systems. This reduced maintenance will result from the higher inherent reliability expected in Option III system modules, which reduces organizational level maintenance requirements and eliminates the need for depot maintenance. Also, the self test and fault isolation capabilities planned to be built into the system should substantially improve control system maintainability and help fault isolation throughout the Mk 71 Mod 0 Gun Mount.

CHAPTER FIVE

STRATEGIC RELIABILITY ANALYSIS

5.1 BASE MISSION ANALYSIS

The strategic reliability model developed in Fleet Analysis Center Report C-1015-8 and described in Section 2.3.3 was used to evaluate the strategic reliability of the Mk 71 Mod 0 Gun Mount, including the control system. System strategic reliability was evaluated against preventive maintenance intervals in order to identify an optimum interval for preventive maintenance. In Report C-1015-8 a two-day maintenance interval was given as optimum for the operating scenario that had the gun mount perform a daily six-minute mission of firing 75 rounds. The model inputs for this single mission evaluation of the Option I control system as taken from Report C-1015-8 are listed in Table 5-1. In that report the optimum strategic reliability for a daily six-minute mission was calculated to be 0.8875, which occurred for a two-day maintenance interval operation.

Table 5-1. INPUT DATA FOR BASE MISSION

Daily Mission: 750 Rounds per Hour for 0.1 Hour

Day	Θ_s	$\overline{M}$	$\overline{M}_p$	ϕ_s	Θ_c	$\overline{M}_c$	t	ϕ_f	Θ_f
1	422	2.1	2.0	23.9	156	1.0	0.1	0.1	0.5693
2	846	2.1	2.0	47.9	156	1.0	0.1	0.2	0.5693
3	1270	2.1	2.0	71.9	156	1.0	0.1	0.3	0.5693
4	1694	2.1	2.0	95.9	156	1.0	0.1	0.4	0.5693
5	2118	2.1	2.0	119.9	156	1.0	0.1	0.5	0.5693
6	2542	2.1	2.0	143.9	156	1.0	0.1	0.6	0.5693
7	2966	2.1	2.0	167.9	156	1.0	0.1	0.7	0.5693

The model described in Technical Report C-1015-8 was applied in this study to evaluate the effect of control system Options II and III on gun mount strategic reliability. The model was used without alteration throughout this analysis. No exhaustive attempt was made to substantiate the applicability of the model developed in Report C-1015-8; however, no

evidence was generated during this study to indicate that this model is not appropriate or has limitations for gun mount analysis.

The model inputs for Option II would be essentially identical to those of Option I. We do not expect significant improvement in the reliability or availability of the Option II control system over Option I. The Option III system, however, will have improved reliability and availability. These will result from the projected increase in the combat critical control system MTBF to 4100 hours and reduction in the control system MTTR to 0.5 hours. The gun mount strategic reliability increased from 0.8875 to 0.8935 for the same two-day maintenance interval with the improved MTBF and MTTR of Option III. This small increase in strategic reliability resulting from a significant increase in the control system MTBF and a large decrease in the control system MTTR is related to the mission selected for evaluation. The mission used in these calculations assumes one six-minute firing mission per day and that the control system is turned on only for this six-minute period each day. Low usage of the control system results in its having a very low effect on the total gun system reliability. Consequently, control system improvements do not substantially contribute to an increase in the strategic reliability for this short-duration mission.

To examine how Mk 71 Mod 0 strategic reliability behaves in general, several different missions were devised and the strategic model was exercised using the data for these missions. The following sections discuss this generalized analysis.

5.2 GENERALIZED MISSION ANALYSIS

Missions supported by large naval guns can range from minutes to hours in duration. Rates of fire may be very high for short periods of time or may be slow for either short or long time periods. For this analysis, various combinations of missions representing high and low intensity combat and long and short duration missions were identified. The missions were categorized by rate of fire, mission duration, and total rounds fired, representing the mission variables required for a thorough analysis. The characteristics of seven missions selected for evaluation are given in Table 5-2.

The relationship of mission characteristics to strategic reliability was determined by exercising the model with varying numbers of rounds fired per hour and daily mission length. The results of this analysis are illustrated for a maintenance interval of two days in Figure 5-1. The figure shows a general, rapid degradation of strategic reliability as mission duration and rounds per hour increase. Similar charts were developed for maintenance intervals of one and three to seven days; they are presented in Appendix C. Comparison of those charts with Figure 5-1 will illustrate the shift in the optimum maintenance interval as mission characteristics change.

The strategic reliability of the gun is affected by the preventive maintenance interval's effect on the loading and firing system of the mount. The study discussed in Technical Report C-1015-8 determined that a maintenance interval of two days was optimal for a 75-round, six-minute mission.

Mission	Rate of Fire (Rounds per Hour)	Mission Duration		Total Mission Rounds Fired
		Hours	Minutes	
Model Baseline	750	0.1	6	75
Study Scenario	600	0.5	30	300
Study Scenario	1	10	600	10
Study Scenario	6	10	600	60
Intensive Support Combat	25	20	1200	500
Intensive Directed Support	100	1	60	100
Typical Support Combat	10	20	1200	200

Table 5-2. DESCRIPTIONS OF EVALUATED MISSIONS

To investigate the effect of this maintenance interval on other missions, the model was used to calculate strategic reliability for the seven missions selected and described in Table 5-2. The results of this analysis for both Option I and Option III are shown in Figure 5-2 with strategic reliability plotted as a function of mission and preventive maintenance interval. The firing rates (in rounds per hour) and the mission durations (in hours) for the seven selected missions are given in parentheses near the pairs of curves in this figure. The lower edge of each curve pair is defined by the strategic reliability plot for the Option I system and the upper edge of each is the plot for Option III. Examination of this figure shows that a two-day interval will maximize or nearly maximize the strategic reliability for all but one mission. The strategic reliability for the mission firing 600 rounds per hour for thirty minutes is maximized at a one-day preventive maintenance interval. That interval will provide a sixteen percent increase in strategic reliability over the two-day interval. Further examination of the model showed that the combination of firing rates of 100 rounds per hour or greater and the firing of more than 100 total rounds would always result in an optimum one-day maintenance interval. However, because this short-duration, rapid-fire type of mission represents only a small percentage of all missions, it is not considered important enough to alter the recommendation for a two-day optimum maintenance interval for the system. Two slow-fire missions, ten rounds in ten hours and twenty-five rounds in twenty hours, are maximized at a seven day maintenance interval. The strategic reliability, however, would only be four to five percent lower for a two-day interval. A comparison of the optimum and two-day interval strategic reliability values for all seven missions of Option III is represented in Table 5-3.

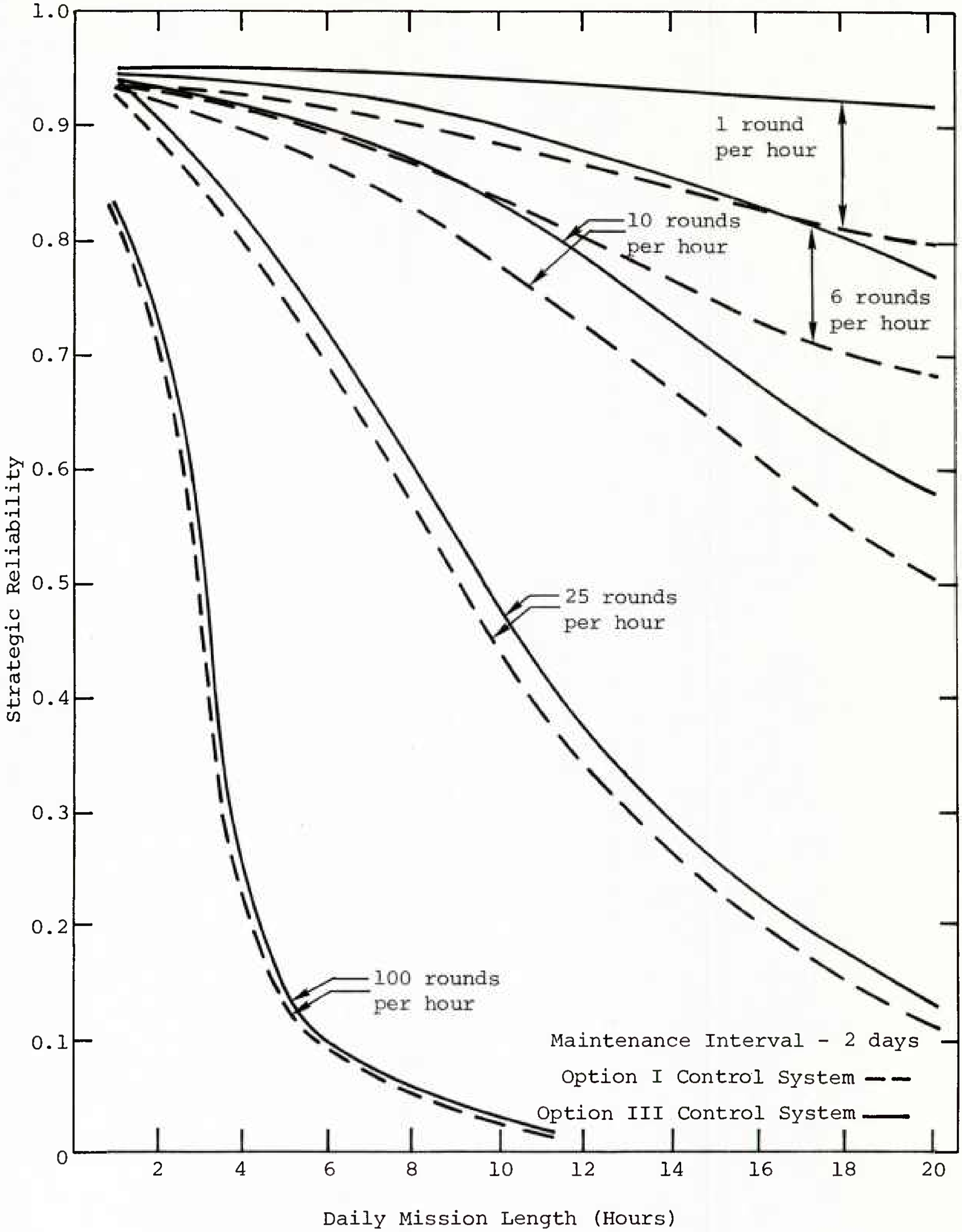


Figure 5-1. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A TWO-DAY PREVENTIVE MAINTENANCE INTERVAL

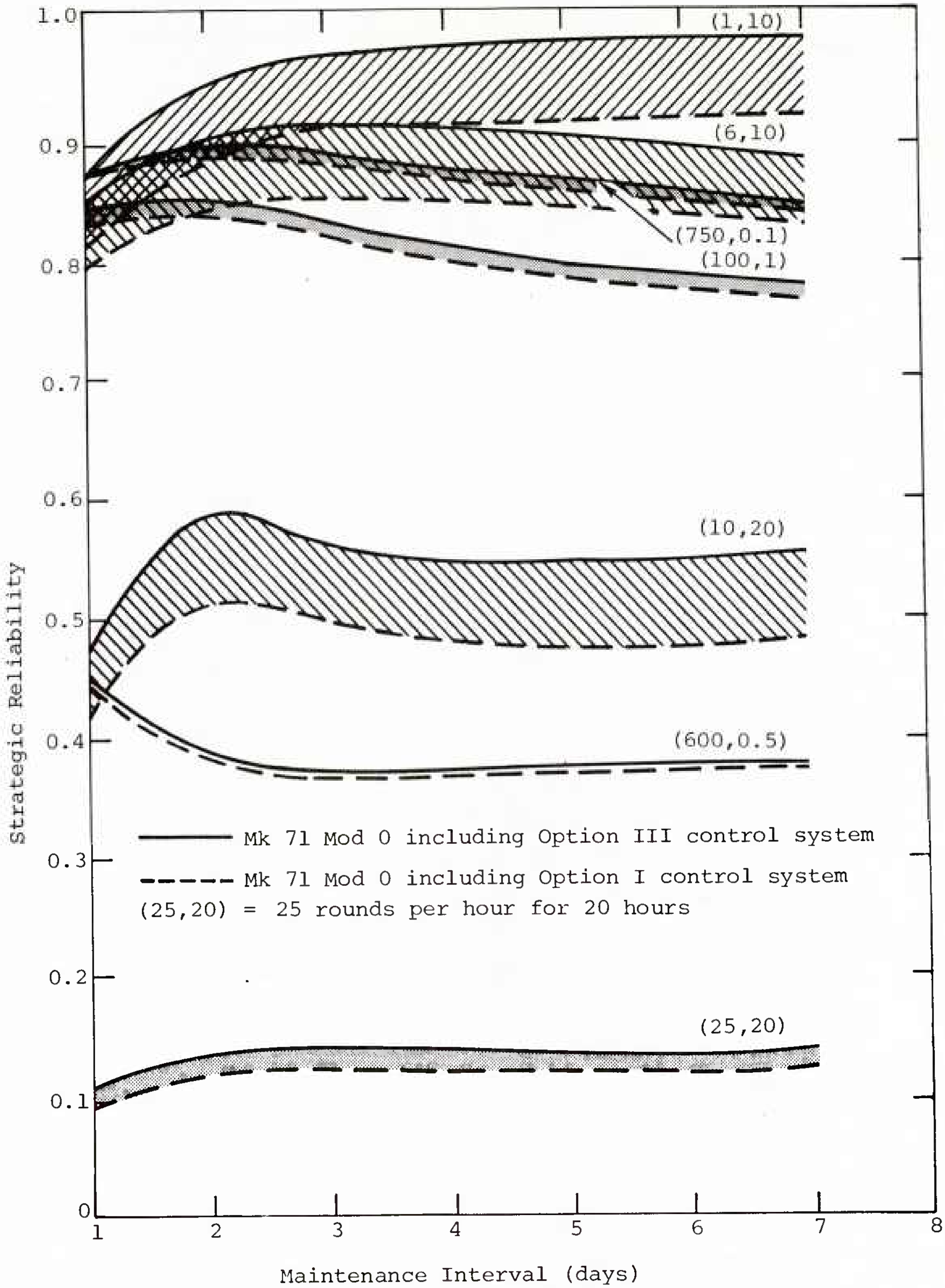


Figure 5-2. MK 71 MOD 0 STRATEGIC RELIABILITY CURVES FOR OPTION I AND OPTION III CONTROL SYSTEMS FOR SELECTED MISSIONS

Table 5-3. STRATEGIC RELIABILITY OF OPTION III FOR OPTIMUM MAINTENANCE INTERVAL					
Mission		Optimum Maintenance Interval (Days)	Strategic Reliability		
Rate of Fire (Rounds/Hours)	Duration (Hours)		Two-Day Interval	Optimum Interval	Percent Increase For Optimum
750	0.1	2	0.8935	0.8935	--
600	0.5	1	0.3854	0.4453	16
1	10	7	0.9464	0.9816	4
6	10	3	0.9049	0.9094	0.5
25	20	7	0.1325	0.1396	5
100	1	2	0.8457	0.8457	--
10	20	2	0.5856	0.5856	--

Examination of Figure 5-2 also indicates that, as could be expected, strategic reliability is directly related to total number of rounds fired. Further, the increase in strategic reliability from using Option III rather than Option I is greatest for the long-duration mission. This reflects the effect of using the more reliable control system for many hours each day, which is a realistic condition expected to occur frequently; the control system is normally on during periods of potential combat whether or not the gun is actually being fired.

5.3 STRATEGIC RELIABILITY MODEL SENSITIVITY ANALYSIS

The model contains a number of variables that could change as a result of gun design changes. It is important to understand the relationship of these variables to the overall gun strategic reliability. Therefore, a model sensitivity analysis was performed to complete this study.

Examination of the model identified ten parameters that should be included in the analysis. Three parameters (mission duration, rounds fired, and preventive maintenance interval) have already been analyzed in Sections 5.1 and 5.2 of this report. The remaining seven parameters are:

- MTTR of Loading and Firing System ($\overline{M}$)
- MTTR of Control System ($\overline{M}_c$)
- Mean Preventive Maintenance Downtime ($\overline{M}_p$)
- MTBF of Control System (Θ_c)
- Mean Rounds Between Failures (MRBF)

- Mean Cycles Between Failures (MCBF)
- Cycles per Preventive Action

The sensitivity of each of these seven parameters was determined by increasing and decreasing their values by fifty percent while holding all other parameters constant. The maintenance interval was also held constant at two days. The results using parameters for the basic mission and the typical support combat mission are presented in Table 5-4 for Option I and Table 5-5 for Option III. Three parameters ($\overline{M}_p$, Θ_c, and MRBF) exhibited a significant effect on Option I, and only two parameters ($\overline{M}_p$, and MRBF) affected Option III. For both options, the effect was greater for the typical support mission, which was based on a larger number of rounds fired and a much longer mission duration. The fifty percent variation of control system MTBF for Option III caused less than one percent change in gun mount strategic reliability. Therefore, further improvement to Θ_c over its Option III value will not have a significant effect on strategic reliability, i.e., strategic reliability was not very sensitive to changes in the Option III control system MTBF.

Table 5-4. STRATEGIC RELIABILITY OF OPTION I (50 PERCENT INPUT VARIATION)

Variable Parameter	Nominal Parameter Value	Change in Strategic Reliability			
		Base Mission 75 Rounds in 6 minutes		Typical Support Mission 200 Rounds in 20 hours	
		Increase (Percent)	Decrease (Percent)	Increase (Percent)	Decrease (Percent)
$\overline{M}$-MTTR of Loading and Firing System	2.1 hour	0	0	0	0
$\overline{M}_c$-MTTR of Control System	1.0 hour	0	0	0	0
$\overline{M}_p$-Mean Preventive Maintenance Downtime	2.0 hour	2	2	3	3
Θ_c-MTBF of Control System	156	0	1	5	13
MRBF-Mean Rounds Between Failures	427	4	18	27	61
MCBF-Mean Cycles Between Failures	530	0	0	0	0
Cycles per Preventive Maintenance Action	30	0	0	0	0

To further understand the influence of $\overline{M}_p$, Θ_c, and MRBF over strategic reliability, strategic reliability was again calculated for maintenance intervals of one through seven days with fifty percent variation in each of these parameter values. The results are illustrated in Figures 5-3 to 5-5. Figure 5-3 shows that preventive maintenance downtime ($\overline{M}_p$) has its

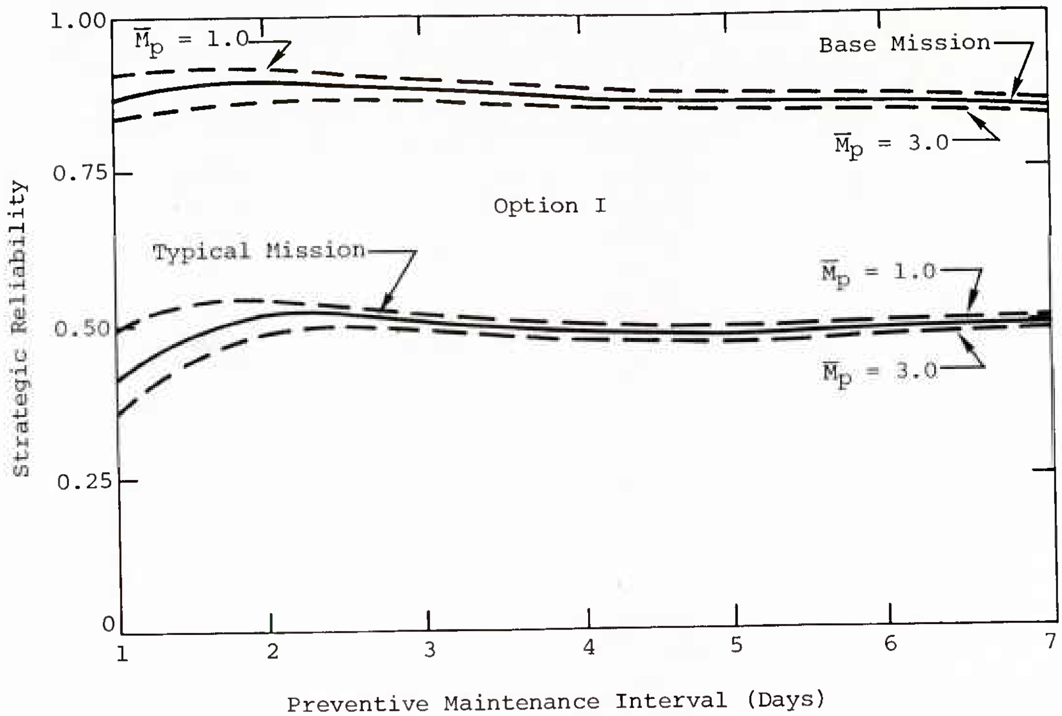
Table 5-5. STRATEGIC RELIABILITY OF OPTION III (50 PERCENT INPUT VARIATION)					
Variable Parameter	Nominal Parameter Value	Change in Strategic Reliability			
		Base Mission 75 Rounds in 6 Minutes		Typical Support Mission 200 Rounds in 20 Hours	
		Increase (Percent)	Decrease (Percent)	Increase (Percent)	Decrease (Percent)
$\overline{M}$-MTTR of Loading and Firing System	2.1 hours	0	0	0	0
$\overline{M}_c$-MTTR of Control System	0.5 hour	0	0	0	0
$\overline{M}_p$-Mean Preventive Maintenance Downtime	2.0 hours	2	2	3	3
Θ_c-MTBF of Control System	4100 hours	0	0	0	0
MRBF-Mean Rounds Between Failures	427	4	18	27	61
MCBF-Mean Cycles Between Failures	530	0	0	0	0
Cycles per Preventive Maintenance Action	30	0	0	0	0

greatest effect for short maintenance intervals; this effect was further explored with the results illustrated in Figure 5-6. Decreasing the value of $\overline{M}_p$ to 0.5 tends to shift the optimum maintenance interval to one day for the base mission, and increasing $\overline{M}_p$ to 5.0 will shift the optimum to three days.

This analysis shows that variations in MRBF have a substantial effect on both options and both missions. The model illustrates that large improvements in strategic reliability can be obtained through increases in MRBF.

5.4 STRATEGIC RELIABILITY ANALYSIS CONCLUSIONS

The analysis described in the preceding three sections shows that the model developed in Technical Report C-1015-8 could be used to evaluate gun mount strategic reliability and determine a maintenance interval that optimizes strategic reliability. This analysis also shows that the optimization calculations in that technical report presented only a portion of the information required for a generalized optimization of the maintenance interval over all types of gun mount missions. However, the optimum two-day preventive maintenance interval appears to apply under a wide range of gun mount missions, particularly support-fire-combat type missions.



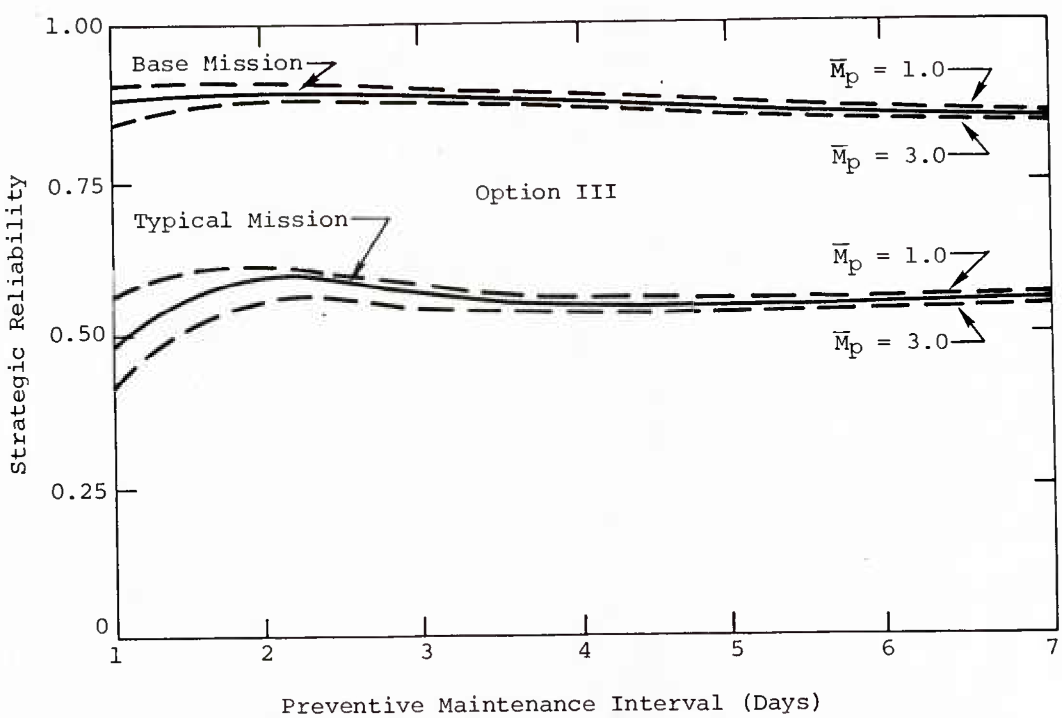


Figure 5-3. STRATEGIC RELIABILITY SENSITIVITY TO THE MEAN PREVENTIVE MAINTENANCE DOWNTIME, $\overline{M}_p$, FOR OPTIONS I AND III

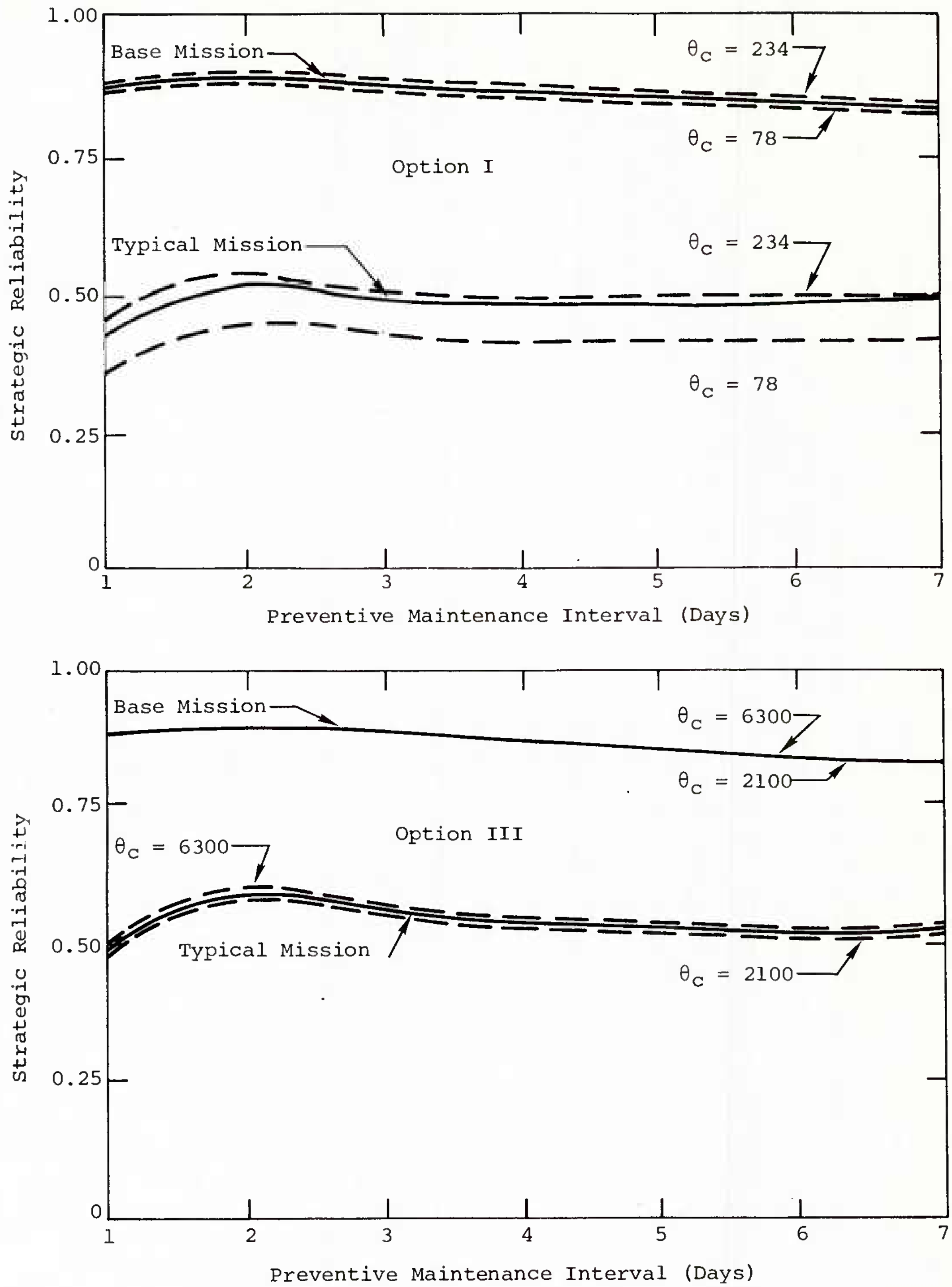


Figure 5-4. STRATEGIC RELIABILITY SENSITIVITY TO THE MEAN TIME BETWEEN CONTROL SYSTEM FAILURES, θ_c, FOR OPTIONS I AND III

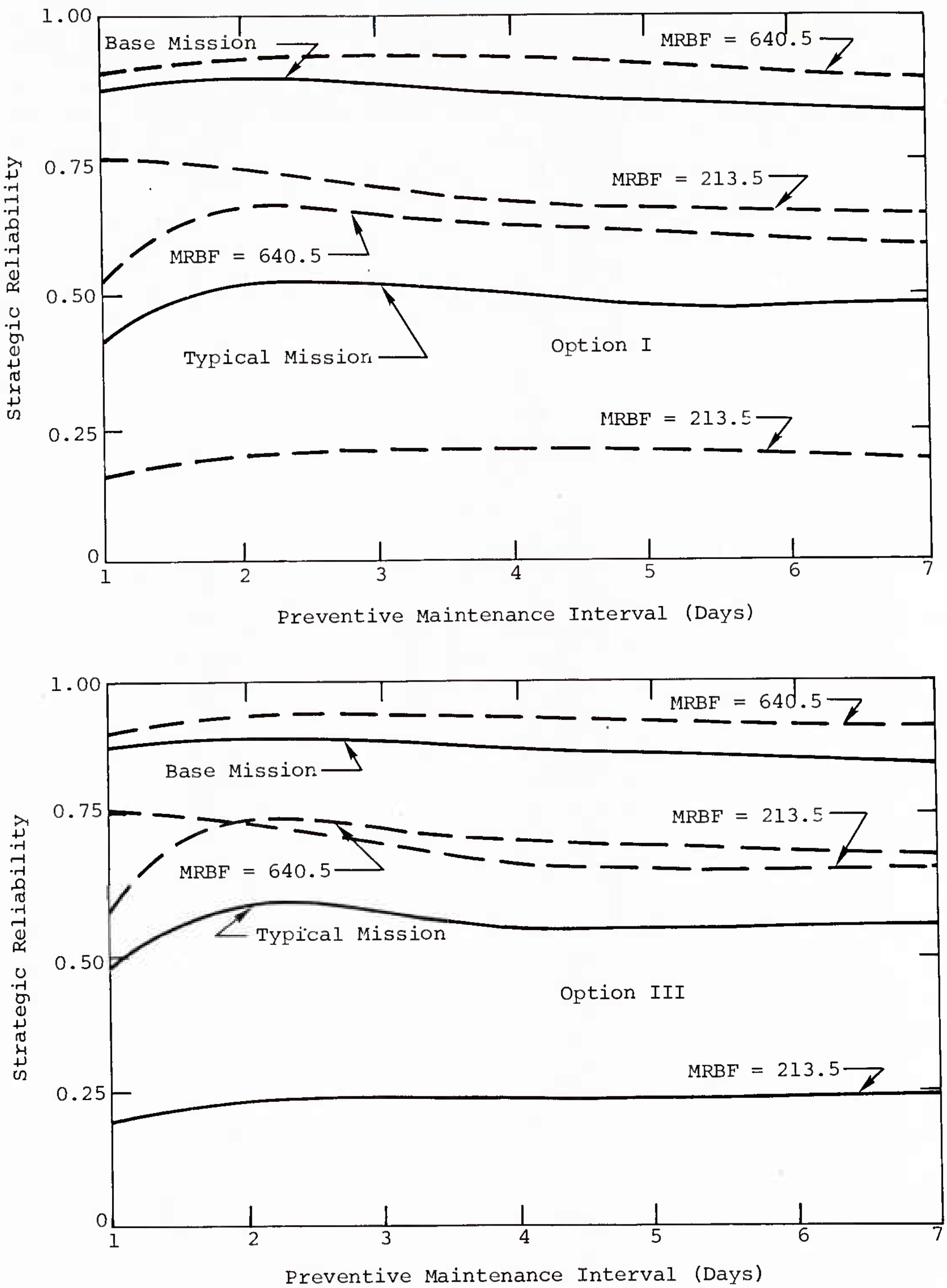


Figure 5-5. STRATEGIC RELIABILITY SENSITIVITY TO MEAN ROUNDS BETWEEN FAILURES, MRBF, FOR OPTIONS I AND III

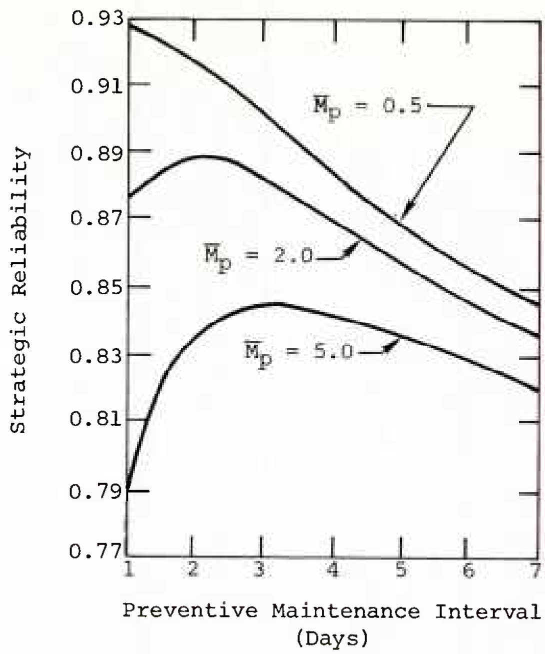


Figure 5-6. STRATEGIC RELIABILITY FOR EXTREME CHANGES IN MEAN PREVENTIVE MAINTENANCE DOWNTIME, $\overline{M}_p$

Additionally, this analysis shows that strategic reliability is most sensitive to the preventive maintenance downtime, control system MTBF, and the gun mount MRBF. The difference in the level of sensitivity to control system MTBF between Options I and III indicates that the further improvements above that of Option III will not sutstantially improve overall gun mount strategic reliability.

Finally, this analysis demonstrates that the Option III control system would generally improve the gun mount strategic reliability. However, the degree of improvement will depend on the long-term mission scenario of the Mk 71 Mod 0 Gun Mount.

CHAPTER SIX

COST ANALYSIS

6.1 COST MODEL DATA AND ASSUMPTIONS

To minimize the information gathering requirements for this study, data were collected and costs calculated only for those items projected to have differing cost values among the three system options being studied. While a comparison using only these differing costs does not address total life cycle cost, it does provide sufficient cost information to determine the relative cost advantages of each of the three systems being studied. When plotted against the number of systems purchased, these costs will display crossover points at the same system quantities as on a total life cycle cost graph. The existing cost projections for the Option I system were used as a baseline for this study. Except as discussed below, production and operational program phase costs for management and labor are considered to be substantially the same for all three system options. Development phase costs are as described below for the Option II and Option III systems. Validation program phase costs are not considered applicable to this study.

6.1.1 Development Cost Data

Non-recurring development costs for this study are discussed below for each control system option. Table 6-1 summarizes these costs for all three options. No recurring costs apply to system development.

6.1.1.1 Option I Data for Development

The Option I control system is the existing control system now installed in the prototype Mk 71 Mod 0 Gun Mount. No further development phase costs are applicable to this system option for this study. All such costs have been previously expended.

6.1.1.2 Option II Data for Development

Option II development costs for contractor engineering are taken from FMC/NOD Letter Number 0034-76.08, dated 20 May 1976. This letter describes the costs for a series of modifications to the existing gun mount that were the subject of Task 1-25 of Mk 71 Mod 0 Support Services Contract Number N00197-76-C-0034. Costs for contractor management, contractor engineering, prototype hardware, documentation, government program management, and

Table 6-1. DEVELOPMENT PHASE LIFE CYCLE COST STUDY DATA SUMMARY (In Thousands of Dollars)

Cost Item	Option I*	Option II	Option III
Contractor Management	0	100	0**
Contractor Engineering	0	272	645
Prototype Hardware	0	150	350
Software	0	0	445
Test and Evaluation	0	0	0**
Documentation	0	200	400
Support and Test Equipment	0	0	0**
Government Program Management	0	150	320
Training	N/A	N/A	N/A
Test Site Activation	N/A	N/A	N/A
Prototype Test and Evaluation	0	100	399
Total Development Costs	0	972	2559

*No Option I development costs are considered in this study.
**Costs for these items are included in other costs in this table.

prototype test and evaluation were defined by NOSL. No new development costs are expected to be encountered for the Order Signal Generator to be used with the Option II system. The non-recurring costs estimated for a transition to the Option II system are $100,000 for contractor management, $272,000 for contractor engineering, $150,000 for prototype hardware, $200,000 for documentation, $150,000 for government program management, and $100,000 for prototype test and evaluation.

6.1.1.3 Option III Data for Development

An estimate of the costs for development of an Option III, microprocessor-based control system for the Mk 71 Mod 0 Gun Mount is given in GSEC/NOSL Report R228. These costs were used as the basis for the Option III cost data. The system discussed in the R228 is a single-processor-based system. Therefore, several of the costs given were increased to reflect expected costs for the triple processor control system design outlined in Section 2.2.3. Government program management was increased to $320,000. System design cost was increased to $645,000, which includes both contractor engineering and management costs. The cost of prototype hardware was estimated to be $350,000. Documentation costs were increased to $400,000 from $300,000. Software development costs were estimated to be $445,000 rather than the $125,000 given in Report R228 (see Section 2 of Appendix D). Prototype test and evaluation costs were estimated to be $399,000, which includes all test and evaluation costs and required support and test equipment.

6.1.2 Production Cost Data

The cost of Mk 71 Mod 0 Gun Mount Control System production has been limited to system hardware costs, support and test equipment acquisition costs, equipment spares costs, and logistic support start-up costs. All other production costs for the three control system options are considered to be equal. The production costs used in this study are detailed in the three sections below and are summarized in Table 6-2. All production costs are considered to be non-recurring investment-type costs.

Table 6-2. LIFE CYCLE COST STUDY DATA SUMMARY FOR THE PRODUCTION PHASE (In Thousands of Dollars)

Cost Item	Option I	Option II	Option III
Production Program Management	N/A	N/A	N/A
Production Hardware	84*	66*	46.4*
Support and Services	N/A	N/A	N/A
Test and Evaluation	N/A	N/A	N/A
Transportation	N/A	N/A	N/A
Installation and Checkout	N/A	N/A	N/A
S&TE Acquisition	91.2*	91.2*	100
Equipment Spares	12*	12*	8.9*
S&TE Spares	N/A	N/A	N/A
NSN Entry Into Supply System	1.6	1.6	2.9
Facilities	N/A	N/A	N/A
Documentation	N/A	N/A	N/A
Training	N/A	N/A	N/A
Total Production Costs			
Fixed Costs	1.6	1.6	102.9
Costs per Mount	187.2	169.2	55.3

*Per Mount.

Based on FMC/NOD cost estimates for Mk 71 Mod 0 Control System conversion to SEM logic or SEM microprocessor-based control, a 95 percent cumulative average learning curve is being applied to all system production hardware costs in this study. The use of this learning curve implies that as the total production quantity of control systems increases, the manufacturing process is expected to become more efficient. Specifically, this 95 percent learning curve is defined to mean that doubling the production quantity decreases the overall hardware cost per control system by 5 percent. For example, if the per-system hardware cost for one Mk 71 Mod 0 Control System is $300,000, the cost per system of a production lot of two systems will be $285,000.

Likewise, the per-system cost when producing four systems will be $270,750 and for eight systems the per-system cost will drop to $257,212. Figure 6-1 shows the 95 percent learning curve for this study, which gives per-system cost as a percentage of the cost of the first system's cost for production quantities from 1 to 64 systems.

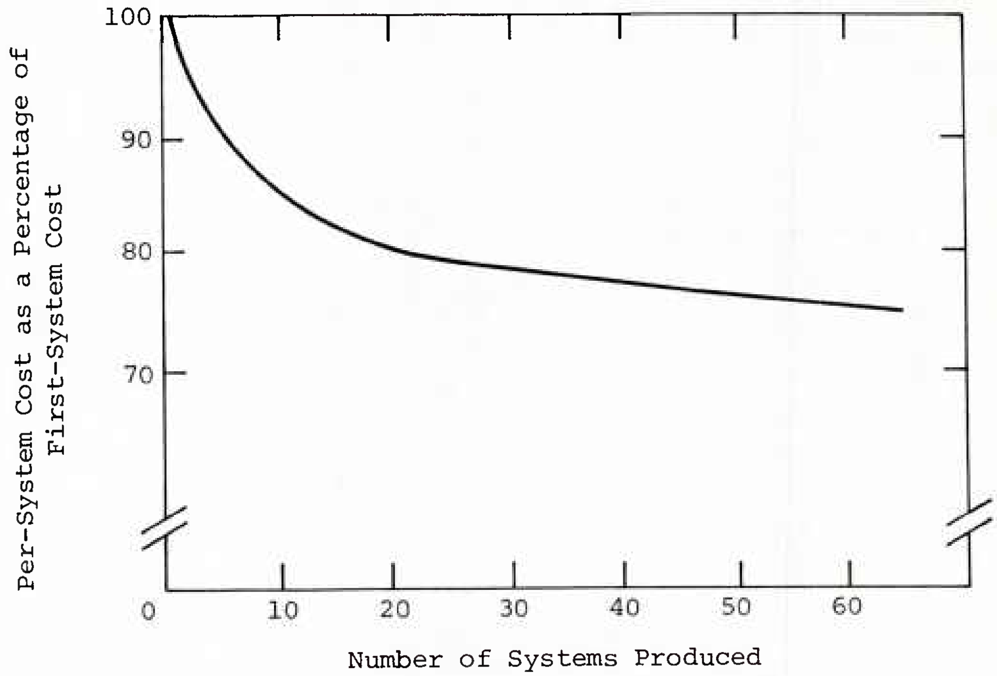


Figure 6-1. NINETY-FIVE PERCENT LEARNING CURVE

6.1.2.1 Option I Data for Production

Cost data for Option I control system production hardware and spares was derived from information provided by GSEC/NOSL. This information contained a description of the circuit boards needed for the existing Mk 71 Mod 0 Control System, and defined the source for board failure rates. Also, this presentation defined an initial spares suite for the existing system. In addition, an estimate was made of the hardware costs for system support equipment and for initialization of system and support hardware into the supply system. System hardware cost was estimated at $84,000 per mount; support and test equipment acquisition was estimated at $91,200 per mount; system spares hardware were estimated to cost $12,000 per mount; and logistics start-up was estimated to require a one time cost of $1,600.

6.1.2.2 Option II Data for Production

The costs for the Option II system production are considered to be identical to the costs for Option I production, except for actual system production hardware costs. On the basis of the costs given in FMC/NOD Letter Number 0034-76-08, production hardware for the Option II system is expected to cost approximately $18,000 less than Option I production hardware.

Therefore, an estimate of $66,000 was used as the hardware production cost for Option II.

6.1.2.3 Option III Data for Production

The Standard Electronic Modules that make up one microprocessor-based control system are listed in Table 6-3. The costs for these modules (taken from SEM program documentation or from engineering estimates used for SEM development at the Naval Avionic Center, Indianapolis, Indiana) are also given in this table along with suggested module spares quantities based on a control system operating requirement of ten hours per day. An estimate is given for the expected number of failures of each module type per system per year and the expected annual cost for replacement of failed modules. It is estimated that per system hardware costs for a triple microprocessor SEM control system for the Mk 71 Mod 0 Gun Mount would be $46,400 and system spares would cost $8,900.

Table 6-3. COST AND SPARES INFORMATION FOR THE OPTION III MICROPROCESSOR-BASED CONTROL SYSTEM SEM MODULES

Module Type	Cost Each (Dollars)	Quantity Per System	Module Failure Rate Per Million Hours	Expected Annual Failure Quantity At 10 Hours Daily Operations	Expected Annual Replacement Cost (Dollars)	Spares Per System	Spares Cost (Dollars)
BYF	150	3	8.300	0.090	13.43	2	300
CMH	36	6	0.450	0.010	0.35	2	72
EHR	200	3	1.000	0.011	2.19	2	400
EMF	54	18	0.230	0.270	14.58	2	108
GDJ	63	3	1.800	0.020	1.24	2	126
GPP	2,200	3	9.300	0.100	220.28	2	4,400
GQB	200	3	0.108	0.001	0.24	2	400
GVQ	130	3	0.280	0.003	0.40	2	260
GYC	273	90	1.000	0.328	89.52	3	819
HRH	190	3	4.000	0.043	8.26	2	380
HRK	150	5	2.000	0.179	26.88	2	300
JDJ	55	99	0.330	0.119	6.55	3	165
JRH	200	3	4.000	0.129	25.71	2	400
LDC	31	6	0.180	0.004	0.12	2	62
LDQ	33	9	0.450	0.015	0.49	2	66
QBA	69	37	0.500	0.067	4.65	2	138
UMU	144	5	1.300	0.117	16.88	2	288
Special 1	100	7	1.100	0.028	2.80	2	200
System Totals	46,408		268		434		8,884

Additionally, it is expected that a minimum of two software development systems will be required to support a microprocessor-based control system production effort. The non-recurring cost for these two software support equipments is estimated to be $100,000. Logistic start-up costs for this microprocessor-based control system have been estimated at $2,900.

6.1.3 Operation and Support Cost Data

Cost data items for operation and support of the Mk 71 Mod 0 Control System have been limited to costs for software maintenance, Organization/Intermediate (O/I) and depot corrective maintenance labor, corrective maintenance material, replenishment spares, and supply systems management. All other operation and support costs are estimated to be equal for all three control system options. The costs in this section were calculated using $25 per hour for depot and O/I maintenance, $350 logistics cost per failure, $20 hardware cost for each depot repair, and a 10 percent replenishment rate on failures of repairable hardware modules. The operation and support costs for this study are detailed below, with Table 6-4 giving a summary of these costs. All operation and support costs are recurring costs.

Table 6-4. OPERATION AND SUPPORT LIFE CYCLE COST STUDY DATA SUMMARY

Cost Item	Option I	Option II	Option III
Personnel	N/A	N/A	N/A
Facilities	N/A	N/A	N/A
Energy Consumption	N/A	N/A	N/A
Material Consumption	N/A	N/A	N/A
Software Maintenance	0	0	$12,500 per year
O/I Corrective Maintenance	$125 per mount per year	$125 per mount per year	$25 per mount per year
Depot Corrective Maintenance	$500 per mount per year	$500 per mount per year	0
Repair Material	$100 per mount per year	$100 per mount per year	$434 per mount per year
Transportation and Packaging	N/A	N/A	N/A
Preventive Maintenance	N/A	N/A	N/A
Overhaul Maintenance	N/A	N/A	N/A
Support and Test Equipment Maintenance	N/A	N/A	N/A
Facilities for Maintenance	N/A	N/A	N/A
Documentation Maintenance	N/A	N/A	N/A
Replenishment Spares	$200 per mount per year	$200 per mount per year	0
Supply System Management	$1,750 per mount per year	$1,750 per mount per year	$350 per mount per year
Training	N/A	N/A	N/A
Termination	N/A	N/A	N/A
Total Operation and Support Costs	$2,675 per mount per year	$2,675 per mount per year	$12,500 per year $809 per mount per year

6.1.3.1 Option I Data for Operation and Support

Table 3-1 summarizes the circuit card failure rates for each type of card in the system. From this information and the information in Section 6.1.3, annual costs per system for Option I operation and support are estimated to be $125 for O/I level corrective maintenance, $500 for depot level corrective maintenance, $100 for repair material, $200 for replenishment spares (ten percent replenishment rate), and $1,750 for supply system management support.

6.1.3.2 Option II Data for Operation and Support

Operation and support costs for the Option II Mk 71 Mod 0 Gun Mount Control System are considered to be identical to those of the Option I system.

6.1.3.3 Option III Data for Operation and Support

The expected annual hardware replacement cost of $434 for the Option III Control System is given as a summary figure in Table 6-3. No depot level support or replenishment spares costs are expected for this system because all SEMs are designed as non-repairable, throw-away modules. An annual software maintenance cost of $12,500, which represents one-quarter man-year of labor, is estimated for Option III. Annual O/I corrective maintenance cost is calculated to be $25 and supply system management cost is estimated at $350.

6.2 CONTROL SYSTEM COST ANALYSIS

Table 6-5 summarizes the cost data used to calculate the control system life cycle costs in this study. These costs were combined using the general formula given below which resulted in the three specific cost equations also shown below. These equations are based on a mission requirement of ten hours of daily operation and a ten-year system life cycle.

Life Cycle Cost = Fixed Non-Recurring Cost + Fixed Recurring Cost × Years in Life Cycle + [Variable Recurring Cost × Years in Life Cycle + (Variable Non-Recurring Cost × Learning Factor)] × Number of Systems

where

LCC_X = Life cycle cost

N = Total number of systems to be produced

$F(N)$ = Cost reduction factor of a cumulative 95 percent learning curve for N systems (applied to production costs only)

Table 6-5. COST DATA SUMMARY (IN DOLLARS)						
Program Phase	Option I		Option II		Option III	
	Non-Recurring	Recurring	Non-Recurring	Recurring	Non-Recurring	Recurring
Validation	0	0	0	0	0	0
Development						
(Fixed Non-Recurring)	0	0	972,000	0	2,559,000	0
Production						
(Fixed Non-Recurring)	1,600	0	1,600	0	102,900	0
(Variable Non-Recurring)	187,200	0	169,200	0	55,300	0
Operation and Support						
(Fixed Recurring)	0	0	0	0	0	12,500
(Variable Recurring)	0	2,675	0	2,675	0	809
Total Fixed	1,600	0	973,600	0	2,661,900	12,500
Total Variable	187,200	2,675	169,200	2,675	55,300	809

$$\text{Option I} \quad LCC_{I} = 1.6K + [26.75K + (187.2K \times F[N])] \times N$$

$$\text{Option II} \quad LCC_{II} = 973.6K + [26.75K + (169.2K \times F[N])] \times N$$

$$\text{Option III} \quad LCC_{III} = 2{,}786.9K + [8.09K + (55.3K \times F[N])] \times N$$

In developing these equations it was assumed that the total number of systems manufactured are produced and put into operation at the start of the ten-year life cycle for which the costs are calculated. Also, each of the system's recurring costs was multiplied by ten to reflect this ten-year life cycle in these equations. Using the above equations, life cycle costs were calculated and are graphed versus system production quantity in Figure 6-2. The curves given in the figure represent system costs for those items in the system cost that are expected to differ among Options I, II, and III. These costs are related to total life cycle costs in such a way that the cross-over quantities shown in these curves and total life cycle cost curves are identical. From these curves it can be seen that Option I costs less than Option II for quantities of concern in this study. It is cheapest to produce Option I control systems if the total number

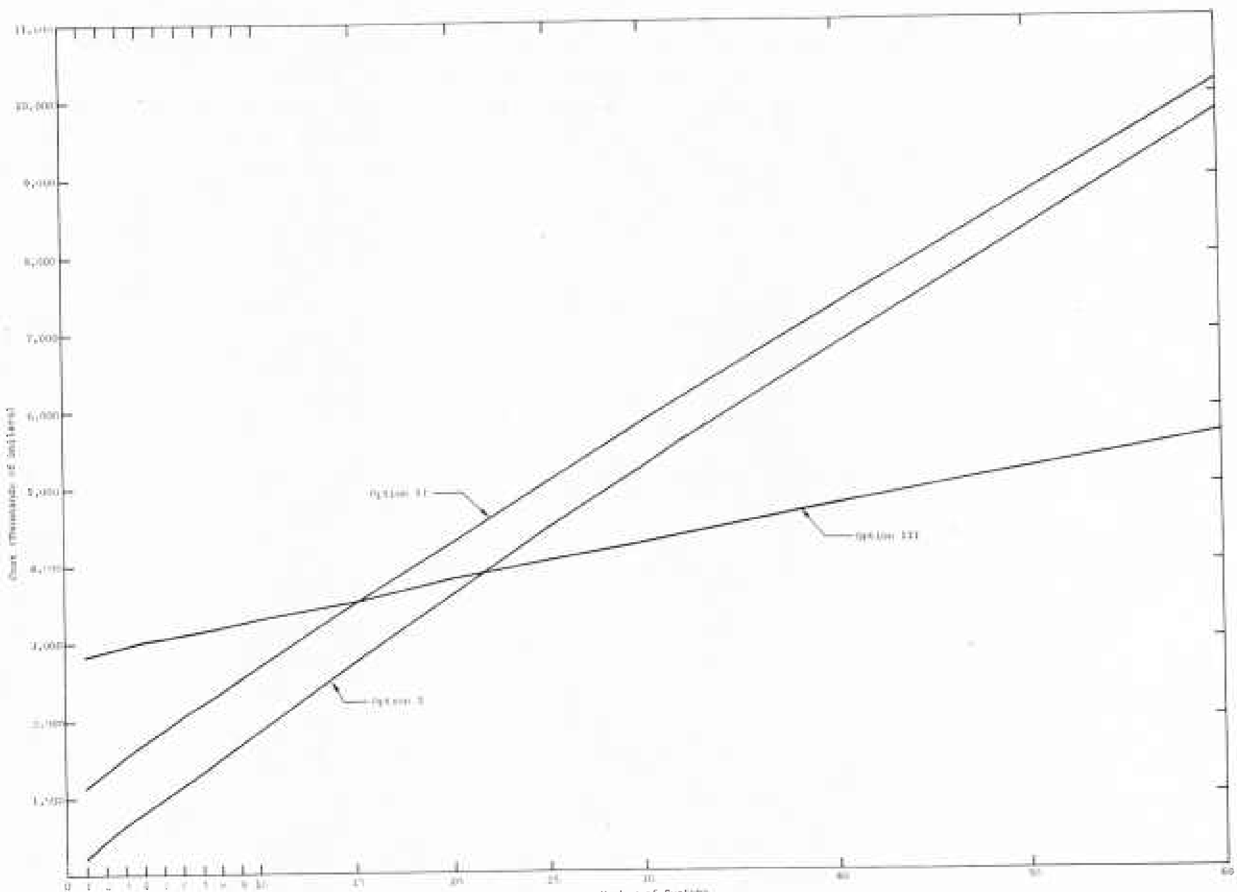


Figure 6-2. SUMMARY COST GRAPH FOR THREE CONTROL SYSTEM OPTIONS

of systems to be manufactured is 21 or less; above 21 systems, Option III provides large cost savings over Options I and II. With system cost as the only decision criterion, Option I systems should be purchased if 21 or fewer systems are needed and Option III systems should be purchased if more than 21 systems are required. However, if other system characteristics, such as reliability, maintainability, and capability, are considered in the trade-off decision between Option I and Option III systems, the procurement of less than 22 Option III systems at a higher life cycle cost may be justified because the Option III system has increased reliability, maintainability, and capability over Option I.

6.3 COST ANALYSIS CONCLUSIONS

In comparing the life cycle costs for the three control system options of the Mk 71 Mod 0 Gun Mount, only those cost elements expected to be substantially different among these systems were considered. Using only these cost elements rather than all cost elements minimized data collection requirements while still providing the information necessary to analyze the cost trade-offs between these systems. Specifically, this analysis shows the Option III system purchase quantities required to obtain a lower life cycle cost than is projected for the Option I control system. From this analysis it was determined that Option I would be least costly if 21 or fewer control systems are to be purchased, and for a total purchase of more than 21 systems, Option III is cheapest. The reduced operating costs for the Option III system offset its development cost if more than 21 systems are produced.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Through this analysis and comparison of reliabilities, maintainabilities, strategic reliability, and life cycle costs of three options for the Mk 71 Mod 0 Control System, the following conclusions have been developed:

- For each of the system characteristics of reliability, maintainability, and strategic reliability, control system Option III is the best system alternative; Options I and II are essentially identical in these characteristics.
- The life cycle costs of the three alternative systems show that Option I is least costly for quantities from one to 21 systems, and Option III for quantities greater than 21.
- The advantages of Option III result primarily from the use of Standard Electronic Modules, which appear to be less costly and substantially more reliable on a function-for-function basis than existing Mk 71 Mod 0 Control System circuitry.
- The strategic reliability model developed in Fleet Analysis Center Report C-1015-8 is useful for Mk 71 Mod 0 system analysis and should be equally useful for all gun mount strategic reliability analysis as well. However, an in-depth verification study of this model could provide useful insights into the subtleties of the model's implications and applications.
- A preventive maintenance interval of two days is optimum for most missions. Gun mount strategic reliability may be degraded up to 16 percent from this two-day maintenance interval, but only for extreme mission scenarios.

7.2 RECOMMENDATIONS

On the basis of this analysis, ARINC Research recommends that a SEM microprocessor control system be developed for the Mk 71 Mod 0 Gun Mount if more than 21 such mounts are to be manufactured, and the program delays caused by development do not counteract the system improvements and cost

savings gained by using a computerized system such as the one outlined in this report. We further recommend that a high degree of management attention be given to all phases of technical development activities for this system. Throughout this development, management should require detailed system definition, specification, and testing to ensure progress, especially in regard to the system software.

Additionally, we recommend that more study be made of the strategic reliability model developed for the Fleet Analysis Center in Technical Report C-1015-8. The utility of this model for determining Mk 71 Mod 0 strategic reliability has been directly proven in this study, but the value of strategic reliability as a system effectiveness parameter was not demonstrated. Other studies should explore this parameter's value as a system measurement, and test the implications resulting from the assumptions used in developing this strategic reliability model.

APPENDIX A

DRAFT REVIEW COMMENTS
FOR
CODE IDENT 57311

Naval Sea Systems Command
Department of the Navy
Critical Item Development Specification
for
Control Console EX___ Mod 0

Dated 6 June 1978

1. INTRODUCTION

Under Contract N00197-76-C-0141 Task Assignment Number Four, ARINC Research Corporation reviewed a draft copy of the Critical Item Development Specification for Control Console EX___ Mod 0, dated 6 June 1978. This draft specification is to be used to guide the design and development of a control system for the production version of the 8"/55 Caliber Mk 71 Mod 0 Gun Mount. In this task, ARINC Research Corporation reviewed the console specification for consistency and completeness and, to the extent possible, for appropriateness of technical details. To accomplish this review, ARINC Research drew on general gun mount knowledge gained through previous contracts concerned with the 3-inch, 5-inch, and other gun systems, and through specific design, safety, reliability, and maintainability experience on the Mk 71 Mod 0 Gun Mount, which was obtained from previous tasks under the current contract N00197-76-C-0141. The results of this specification review are given below. Section 2.1 of this appendix provides generalized comments about the overall specification and to a degree summarizes the specific paragraph-by-paragraph comments given in Section 2.2. Section 3 provides the conclusions and recommendations resulting from the review.

2. REVIEW COMMENTS

2.1 General Summary Comments

Paragraphs 1 and 2 of the Control Console Specification are considered sufficiently detailed, complete, and consistent with the information throughout the remainder of the specification. Paragraph 3, the control console design requirements, addresses the general low-level hardware requirements in much detail and outlines system level functional requirements. This section requires that console operation be based on the capabilities of a microprocessor but does not address the important design aspects of the program software needed for processor operation. Also in Paragraph 3, certain requirements for built-in test equipment (BITE) are identified, but no specific statement is made concerning external system test equipment. The console specification is ambiguous regarding the degree of sophistication required in external test equipment, or whether such equipment can be used.

The specified development requirements identified in Paragraph 4 address the documentation to be generated during the control console development. The hardware documentation requirements in this section are detailed and appear complete. The software documentation requirement simply requests "full design disclosure", which does not seem adequate. Specific software documentation should be required.

Paragraph 5, Inspection Requirements, and Paragraph 6, Testing Requirements, are very sparse and non-specific. Quality inspection requirements are only defined for one console connector assembly; no other assembly or system inspections are specified. The only definitive testing requirements are for shock, vibration, and water survivability. No specific operational, maintenance, or system capability tests are identified. These should be included in Paragraphs 5 and 6 of the specification.

2.2 Detailed Specification Comments

The following discussion provides detailed comments on individual paragraphs within the Development Specification for the Control Console EX___ Mod 0. A specification paragraph is discussed only when it is considered to be deficient in some manner. Paragraphs not mentioned in this discussion are considered to be satisfactory. Information that should be added to the specification is discussed under the paragraph that most appropriately applies to the information.

- Paragraph 3.1, Safety Requirements

The following safety requirements subparagraphs are recommended for inclusion in the EX___ Mod 0 specification:

3.1.1 General Requirements: MIL-STD-454 Requirement 1

3.1.2 Gun Mount Control Safety Requirements:

The Control Console EX___ Mod 0 shall be designed and programmed to safety control the Mk 71 Mod 0 Gun Mount under all operating and maintenance conditions, and to preclude the occurrence of unsafe conditions due to operator error and/or hardware failure within the control system or its interface circuitry. Unsafe conditions shall be deemed to exist whenever a CRITICAL or MAJOR hazard occurs as defined below:

CRITICAL HAZARD - Any situation in which ammunition is not safe, or immediate corrective action is necessary to prevent personal injury.

MAJOR HAZARD - Any situation in which immediate corrective action is necessary to repair or prevent major system damage. Major system damage is considered to be any condition which would require more than ____* man-hours of normal organization level maintenance to restore the gun mount to a combat-ready status.

Specific design safety feature requirements are identified below:

3.1.2.1 No failure of an individual control system component shall cause a CRITICAL or MAJOR hazard condition.

3.1.2.2 No control path, the failure of which would cause a CRITICAL or MAJOR hazard condition, shall have a total predicted hardware failure rate greater than ____* failures per million hours according to the data and prediction methodology of MIL-HDBK-217B.

3.1.2.3 All connector or wiring situations or failures that result in open circuits shall not cause CRITICAL or MAJOR hazard conditions.

3.1.2.4 Loss of power to the gun mount or loss of power to any portion or all of the control console EX___ Mod 0 shall not cause CRITICAL or MAJOR hazard conditions.

3.1.2.5 All hardwired logic functions within the Control Console EX___ Mod 0 shall be accomplished with a minimum of components in keeping with the other requirements listed in this specification.

3.1.2.5 The Control Console EX___ Mod 0 safety shall not be degraded under conditions of maximum power-line noise levels defined for the Mk 71 Mod 0 Gun Mount.

- Paragraph 3.25, Batteries

The requirement for batteries to maintain memory data is considered unnecessary for memory applications in the EX___ Mod 0 Control Console. All program memory in this console should be in read-only memory (ROM). Ammunition/cell data can easily be stored in non-volatile core-type memory.

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*To be defined by NOSL.

Random-access memory (RAM) used for scratch-pad applications should not be required to maintain data through either normal or malfunction-induced system stoppages. Therefore, memory hardware and usage should be required to be battery-free and Paragraph 3.25 should be eliminated or changed to reflect this requirement.

- Paragraph 3.26, Semiconductor Devices

In this paragraph the term "critical circuit areas" should be defined or have a procedure established to allow future definition. To this end it is recommended that the following statement be appended to the existing Paragraph 3.26:

"All semiconductor devices whose failure can cause critical or major safety hazards to exist are considered critical circuits. In addition, semiconductor devices whose failure can seriously degrade the overall gun mount performance are also considered critical circuits. Other critical circuits may be defined during the development process, and all critical circuit components should be specifically identified during the development process. System design should minimize the number of critical circuits."

- Paragraph 3.27, Test Provisions

Subparagraphs to Paragraph 3.27 allude to the allowable use of external support equipment but do not specify the nature of such equipment. Paragraph 3.27.3.1 states that "BITE shall provide for a mean time to repair (MTTR) of 30 minutes or less for any failed processor memory, module, or subassembly." This statement is not clear and should read "... any failed processor or memory module or subassembly." This paragraph also states that "BITE shall be aided by SEM LED modules and readily accessible test points", but it is not clear to what degree this aid should contribute to the required 30 minute MTTR. Paragraph 3.27.3.2 should require that BITE generate a display of gun mount status upon a detected critical path failure. This display should be sufficiently informative to allow the mount operator to immediately decide on an appropriate course of action. This paragraph should also specify the frequency of BITE monitoring.

Paragraph 3.27.3.3 should specify a capability for operator-callable self test and BITE tests.

- Paragraph 3.30, Reliability

The 5000 hour MTBF specified in this paragraph is too high, considering recent reliability estimates made on SEM microprocessor-based gun mount control systems. In a recent estimate (performed by ARINC Research under Contract N00197-76-C-0141, Task Number 3), identified SEM hardware alone were found to give an MTBF below 5000 hours. Additional control system components would decrease this estimate still further. A more realistic MTBF seems to be about 2500 hours. Specifying an MTBF in this range for the control system would still ensure that the Control Console EX__ Mod 0 did not substantially contribute to the overall gun mount MTBF.

• Paragraph 3.38, Maintainability

In addition to the other requirements listed, this paragraph should also identify required support equipment that can be used to achieve a 30-minute MTTR. Support equipment referenced in this paragraph should be consistent with Paragraph 3.27.

• Paragraph 3.46, Microelectronic Devices

This paragraph should be subjected to the same criticality definitions as were identified for semiconductor devices in Paragraph 3.26.

• Paragraph 3.52.6

"RAM" is a standard computer industry acronym that means "Random Access Memory", not "Read Address Memories" as called out in this paragraph. Also, the meaning of the last sentence of this paragraph would be more specific if it were replaced with the following:

> "These memory circuits shall be designed in such a manner that power-line and signal-line noise (including induced switching transients) will not cause alterations in the data in memory."

• Paragraph 3.52.8

The reason for a global requirement for microprocessor isolation specified in this paragraph is not apparent. The value of required isolation circuitry is not clear in light of its possibilities for malfunction.

• Paragraph 4.2, Software

Considering software's importance to the functioning of any computer-based system, this paragraph provides little guidance to the creation of software for the Control Console EX___ Mod 0. As a minimum this paragraph should establish ground rules for software design and development. It should specify a structured, maintainable, and readily expandable software organization; identify the degree of input and output expandability required; establish the required and allowable operator interaction with software; identify or require prior approval of cross-assemblers and other programming aids; and require a minimum of maintenance and user documentation to be generated during software development.

• Paragraph 5, Inspection Requirements

This paragraph should call out a full range of quality inspection requirements in keeping with the requirements defined in Paragraphs 3 and 4. Quality inspections should be given in detail to check for and verify at least minimum acceptable workmanship in each design and development area for the system. In each area reject criteria should be established for quality inspections.

• Paragraph 6, Testing Requirements

Specific testing requirements should be identified to ensure demonstration of a full range of minimum acceptable performance criteria. Also, pass/fail criteria should be specified for each system function called out in the performance test sequence.

3. CONCLUSIONS AND RECOMMENDATIONS

The Critical Item Development Specification for the Control Console EX___ Mod 0 is intended to define system requirements related to top-level system operation, interfacing, testing, and maintenance; system software and documentation; hardware components to be used in system manufacture; system design verification; and quality assurance. From this review it is concluded that the definition of requirements for system operation, interfacing, documentation, and hardware components provides adequate information for these areas of an EX___ Mod 0 Control Console development effort. However, requirements identified for system software, design verification, quality assurance, testing, and maintenance are considered to be too weak to ensure adequate system development. The lack of definitive requirements for design verification throughout the control console's development is considered to make system development under this specification especially vulnerable and potentially costly.

On the basis of this specification review, ARINC Research Corporation recommends that Naval Ordnance Station Louisville provide more detailed requirements for Control Console EX___ Mod 0 development related to system software, design verification, quality assurance, testing, and maintenance before this specification is issued. More detailed recommendations for individual specification paragraphs are given in Section 2. Special attention should be given to the requirements for design verification testing and system software. Comprehensive design verification requirements are needed to ensure adequate system performance under all anticipated conditions of system operation and maintenance. System software is a new area of gun control system technology and is a key to computerized gun system performance. Special attention should be given to its specification and validation.

APPENDIX B

COST EQUATIONS FOR MK 71 MOD 0 CONTROL SYSTEM COMPARISON

The equations given in this appendix were used in calculating life cycle cost elements for Mk 71 Mod 0 control system comparison. The cost elements defined by these equations are summed to calculate a system cost.

CBS 121100*

Contractor management costs during full scale development effort are

$$\sum_{I=1}^{Y} DCPM(I)$$

where

$DCPM(I)$ = contractor management costs in dollars per year
Y = number of years in life cycle

CBS 121200

Contractor engineering costs during full scale development effort is

$$\sum_{I=1}^{Y} DCE(I)$$

where

$DCE(I)$ = contractor engineering costs in dollars per year

CBS 121300

Contractor prototype hardware development costs during full scale development effort are

$$\sum_{I=1}^{Y} DCH(I)$$

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*Cost Element Reference Number from the Life Cycle Cost Guide.

where

DCH(I) = contractor ptototype hardware costs in dollars per year

CBS 121400

Contractor software development costs during full scale development effort are

$$\sum_{I=1}^{Y} DCS(I)$$

where

DCS(I) = contractor software development costs in dollars per year

CBS 121500

Contractor development test and evaluation costs during full scale development effort is

$$\sum_{I=1}^{Y} DCTE(I)$$

where

DCTE(I) = contractor development test and evaluation costs in dollars per year

CBS 121600

Contractor documentation costs during full scale development effort are

$$\sum_{I=1}^{Y} DCD(I)$$

where

DCD(I) = contractor documentation costs in dollars per year

CBS 121700

Contractor support and test equipment development costs during full scale development effort are

$$\sum_{I=1}^{Y} DCST(I)$$

where

$DCST(I)$ = contractor support and test equipment development costs in dollars per year

CBS 122100

Government program management costs during full scale development effort are

$$\sum_{I=1}^{Y} DGPM(I)$$

where

$DGPM(I)$ = program management costs in dollars per year

CBS 122230

Test and evaluation costs incurred by Government during prototype test and evaluation program are

$$\sum_{I=1}^{Y} DGTE(I)$$

where

$DGTE(I)$ = test and evaluation personnel costs in dollars per year

CBS 22100

Production hardware costs of the prime equipment acquisition are

$$\sum_{I=1}^{Y} NN(I) \times CU$$

where

$NN(I)$ = prime equipment annual acceptance schedule in equipments per year

CU = prime equipment procurement price in dollars per equipment

CBS 231000

Acquisition costs of support and test equipment are

$$\sum_{I=1}^{Y} STE(I)$$

where

STE(I) = support and test equipment acquisition costs in dollars per year

CBS 232110

Acquisition cost of primary equipment initial spares is

$$\sum_{I=1}^{Y} NN(I) \times SSC$$

where

NN(I) = prime equipment annual acceptance schedule in equipments per year

SSC = spares suit cost in dollars per system

CBS 232200

Introduction of new NSNs (National Stock Numbers) into the supply system costs are

$$(NSNP + NSNS) \times RIE$$

where

NSNP = number of new NSNs of primary equipment

NSNS = number of new NSNs of support and test equipment

RIE = average NSN entry into the support system cost in dollars per NSN

CBS 315000

Software maintenance costs incurred during the equipment operation are

$$\sum_{I=1}^{Y} CS(I)$$

where

CS(I) = prime equipment software maintenance costs in dollars per year

CBS 321110

O/I level corrective maintenance labor costs for the detection, isolation, removal, and replacement of item failures in the prime equipment are

$$\sum_{I=1}^{Y} N(I) \times EMM$$

where

N(I) = prime equipment inventory in equipments per year
EMM = expected annual cost per system for O/I level corrective maintenance

CBS 321130

Depot level corrective maintenance costs incurred during the repair of a failed item are

$$\sum_{I=1}^{Y} N(I) \times \sum_{K=1}^{NK} OT \times QTY(K) \times LSD(K) \times RSD/R(K)$$

where

N(I) = prime equipment inventory in equipments per year
OT = prime equipment operating time in hours per equipment per year
QTY(K) = quantity of Kth item in quantity per item
LSD(K) = depot maintenance time to repair Kth item in hours per item
RSD = Depot maintenance personnel pay rate in dollars per hour
R(K) = Mean time between failures of Kth item in hours per failure
NK = Total number of system component items

CBS 321200

Corrective maintenance repair material costs are

$$\sum_{I=1}^{Y} N(I) \times \sum_{K=1}^{NK} OT \times QTY(K) \times CST(K) \times FM/R(K)$$

where

$N(I)$ = prime system inventory
OT = prime system operating time in hours per system per year
$QTY(K)$ = quantity of Kth item in quantity per system
$CST(K)$ = unit cost of the Kth item in dollars per item
FM = repair material rate as a percent of item cost (ratio)
$R(K)$ = mean time between failures of Kth item in hours per failure

CBS 327100

Replenishment spares costs are

$$\sum_{I=1}^{Y} N(I) \times \sum_{K=1}^{NK} OT \times QTY(K) \times CST(K) \div R(K)$$

where

$N(I)$ = prime system inventory in systems per year
OT = prime system operating time in hours per system per year
$QTY(K)$ = quantity of Kth item in quantity per item
$CST(K)$ = unit cost of the Kth item in dollars per item
$R(K)$ = mean time between failures of Kth item in hours per failure

CBS 327200

Supply support management costs are

$$\sum_{I=IYI}^{Y} EAR \times CPR$$

where

EAR = expected annual number of repairs per system in quantity per system
CPR = supply support management costs per repair in dollars per repair

APPENDIX C

STRATEGIC RELIABILITY PLOTS AS A FUNCTION OF FIRING RATE, MISSION DURATION, AND PREVENTIVE MAINTENANCE INTERVAL

The graphs in this appendix, Figures C-1 through C-6, show strategic reliability as a function of average gun mount firing rates, mission duration, and the number of days in the preventive maintenance cycle. The graphs show plots of strategic reliability preventive maintenance cycles of 1, 3, 4, 5, 6, and 7 days. The graph for a 2-day preventive maintenance cycle is given in the body of this report as Figure 5-1.

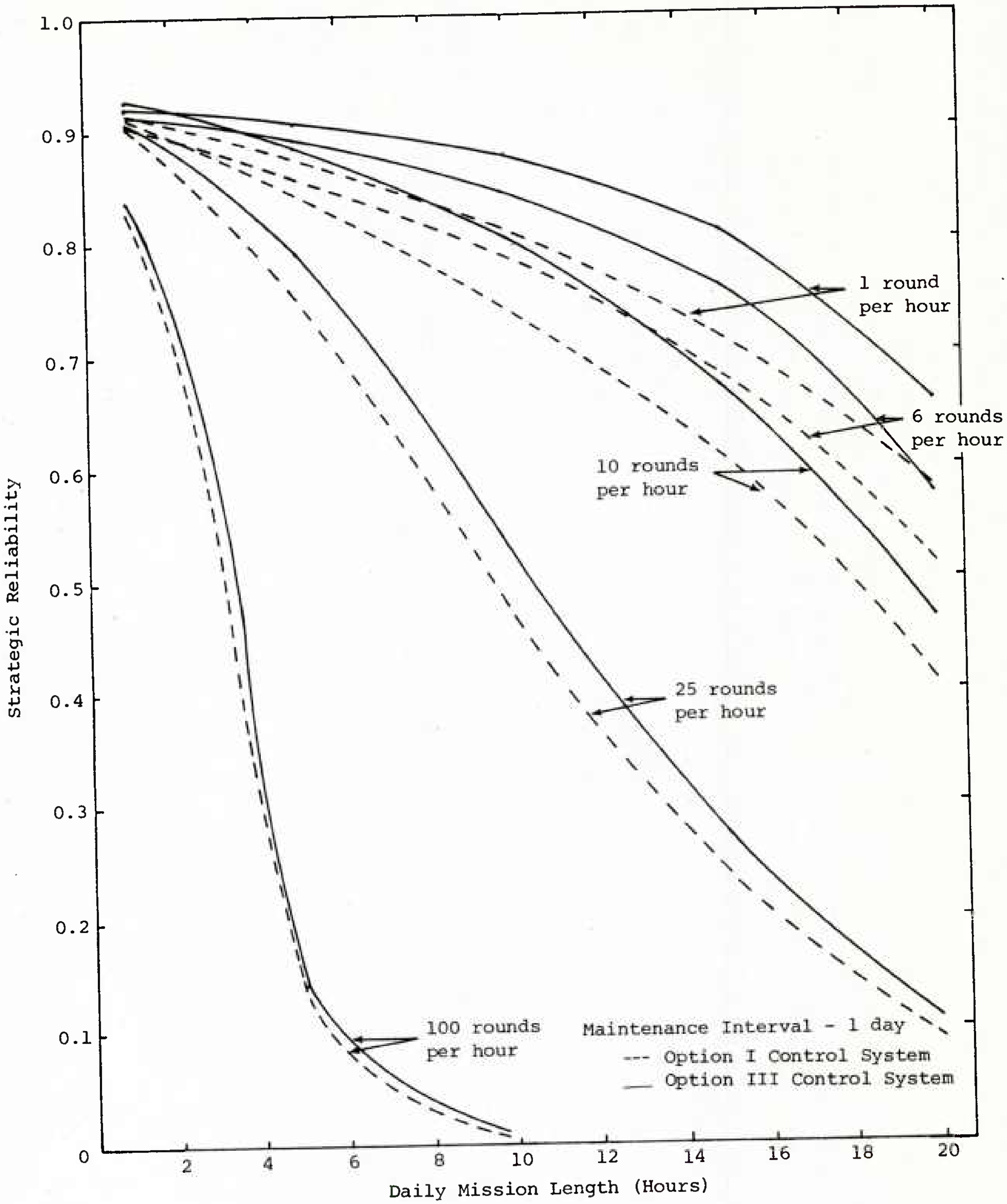

Figure C-1. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A ONE-DAY PREVENTIVE MAINTENANCE INTERVAL

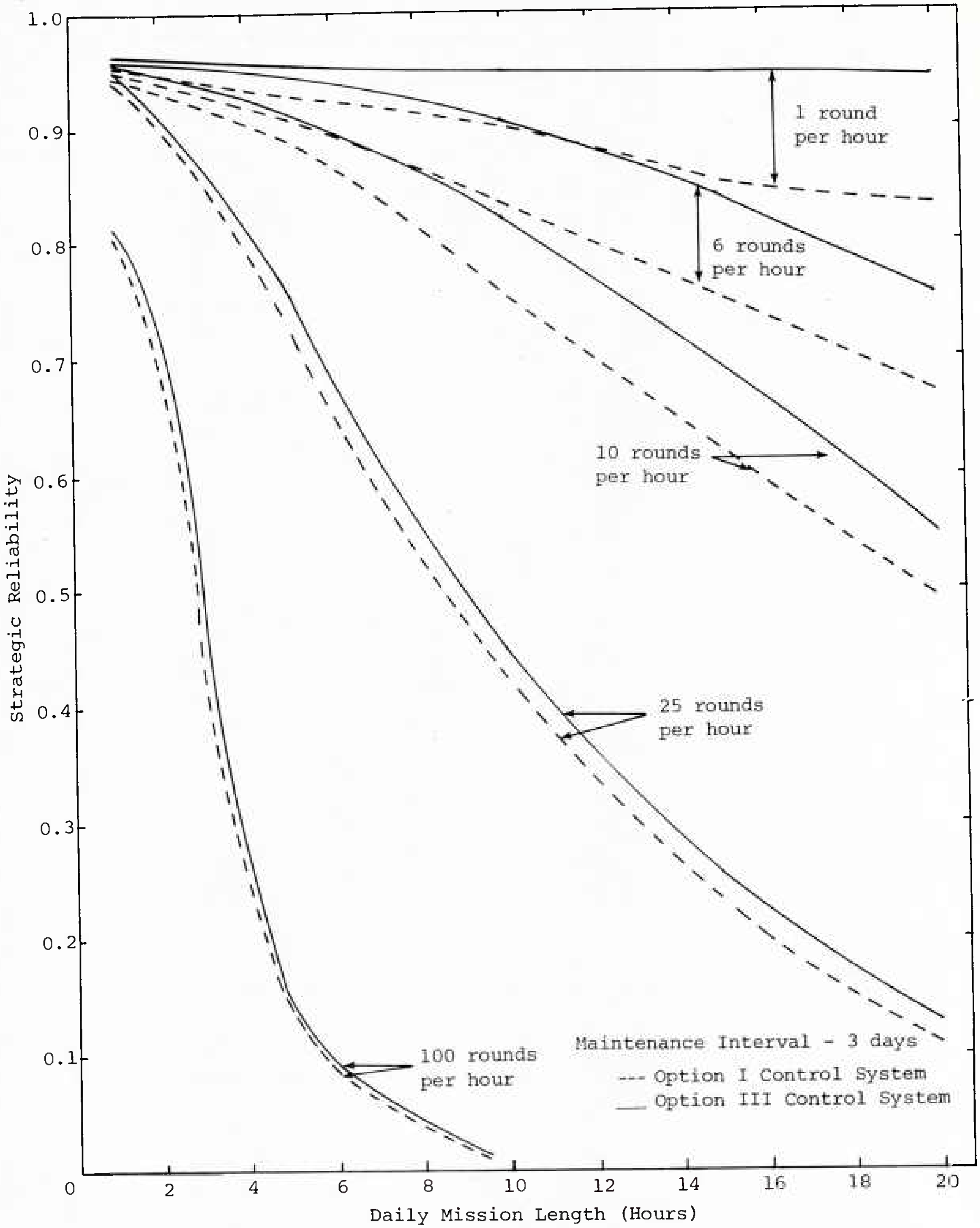

Figure C-2. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A THREE-DAY PREVENTIVE MAINTENANCE INTERVAL

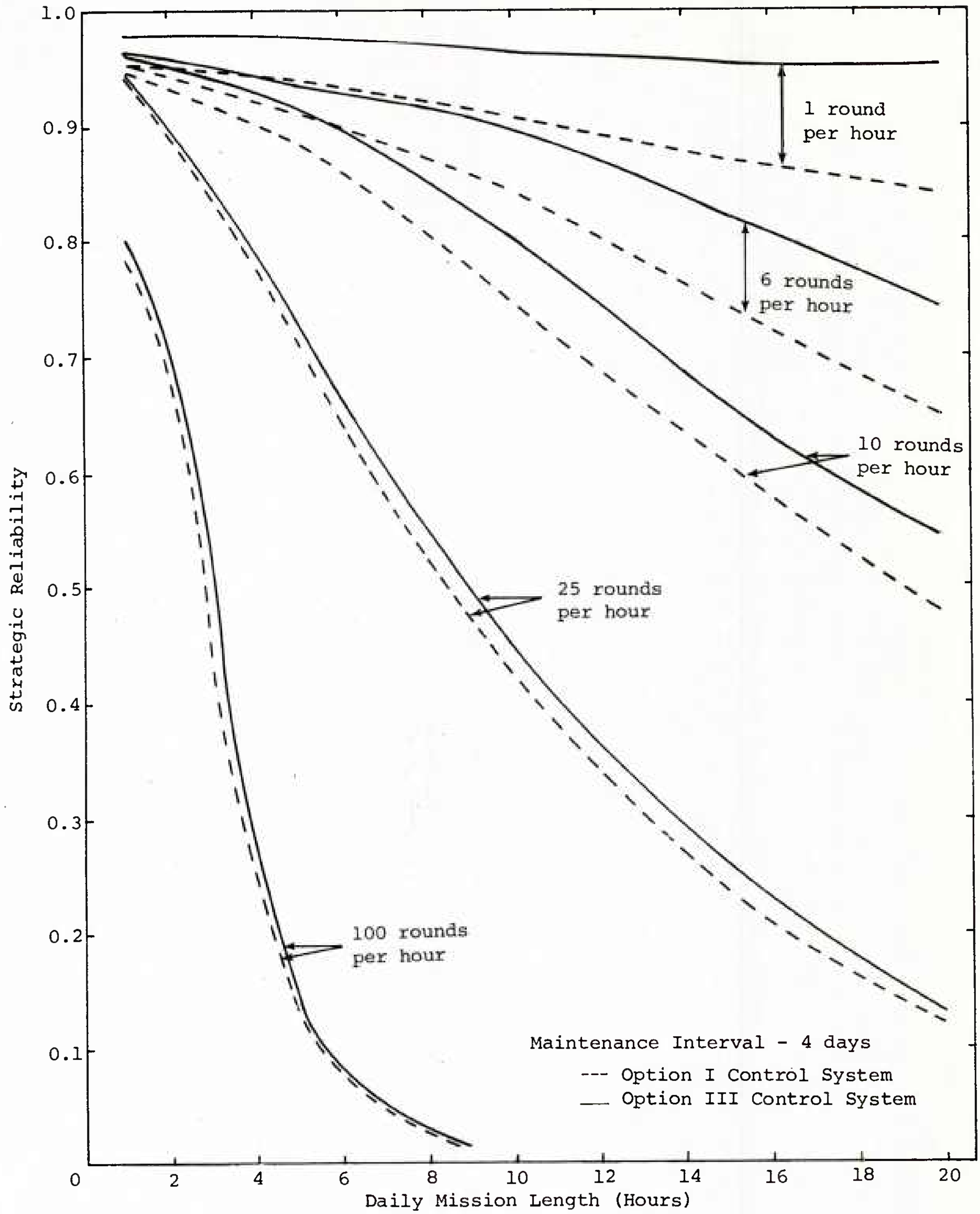

Figure C-3. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A FOUR-DAY PREVENTIVE MAINTENANCE INTERVAL

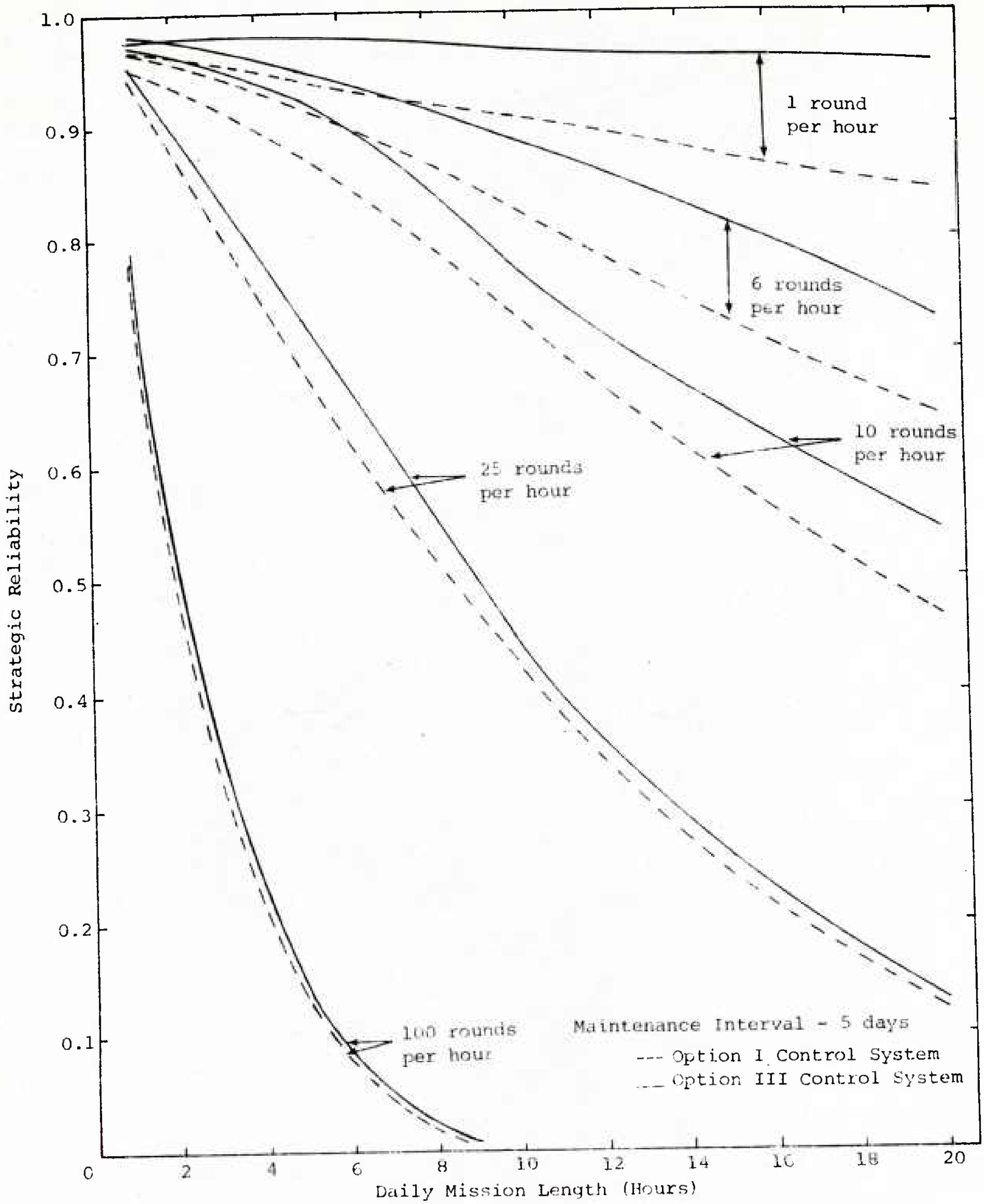

Figure C-4. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A FIVE-DAY PREVENTIVE MAINTENANCE INTERVAL

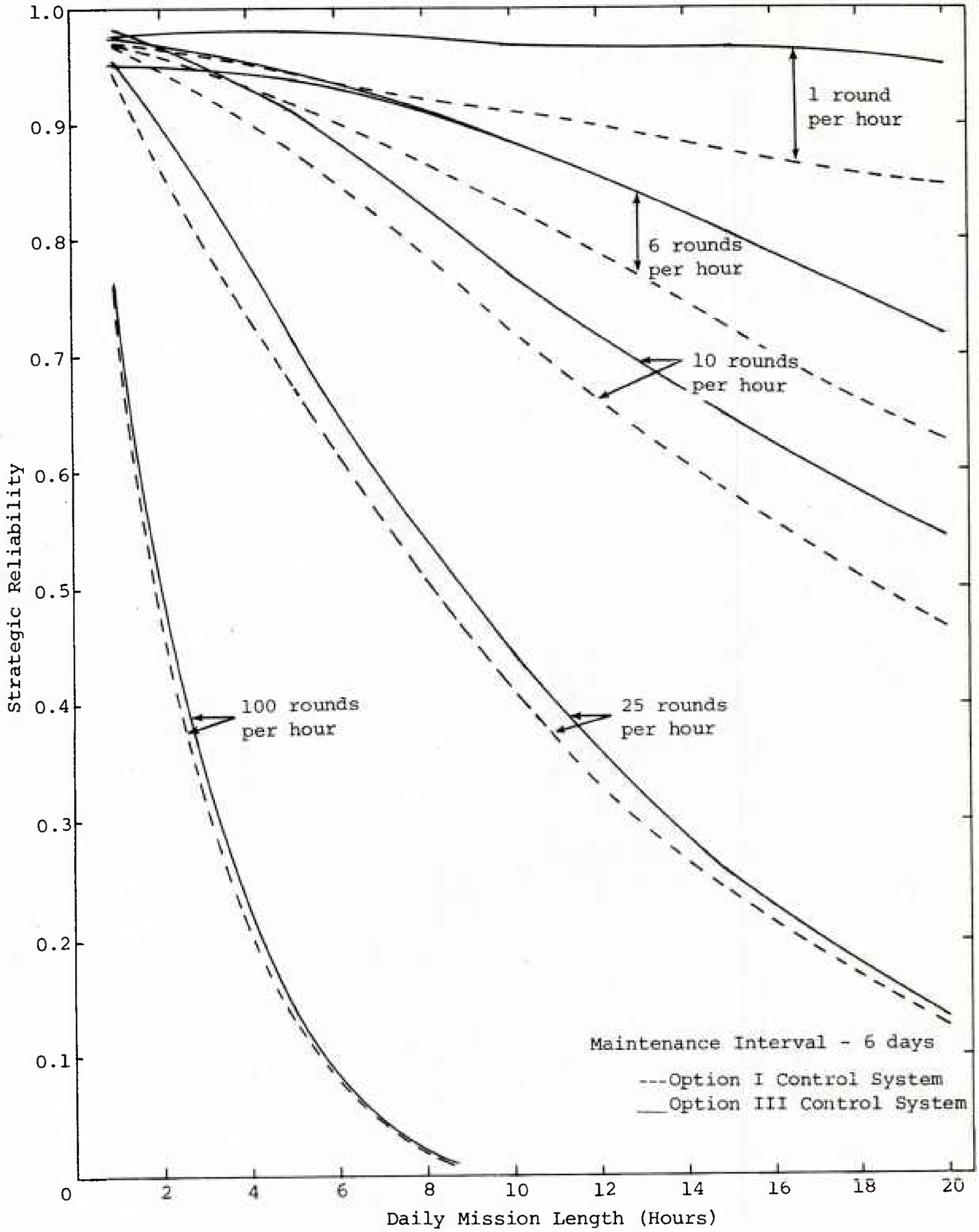

Figure C-5. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A SIX-DAY PREVENTIVE MAINTENANCE INTERVAL

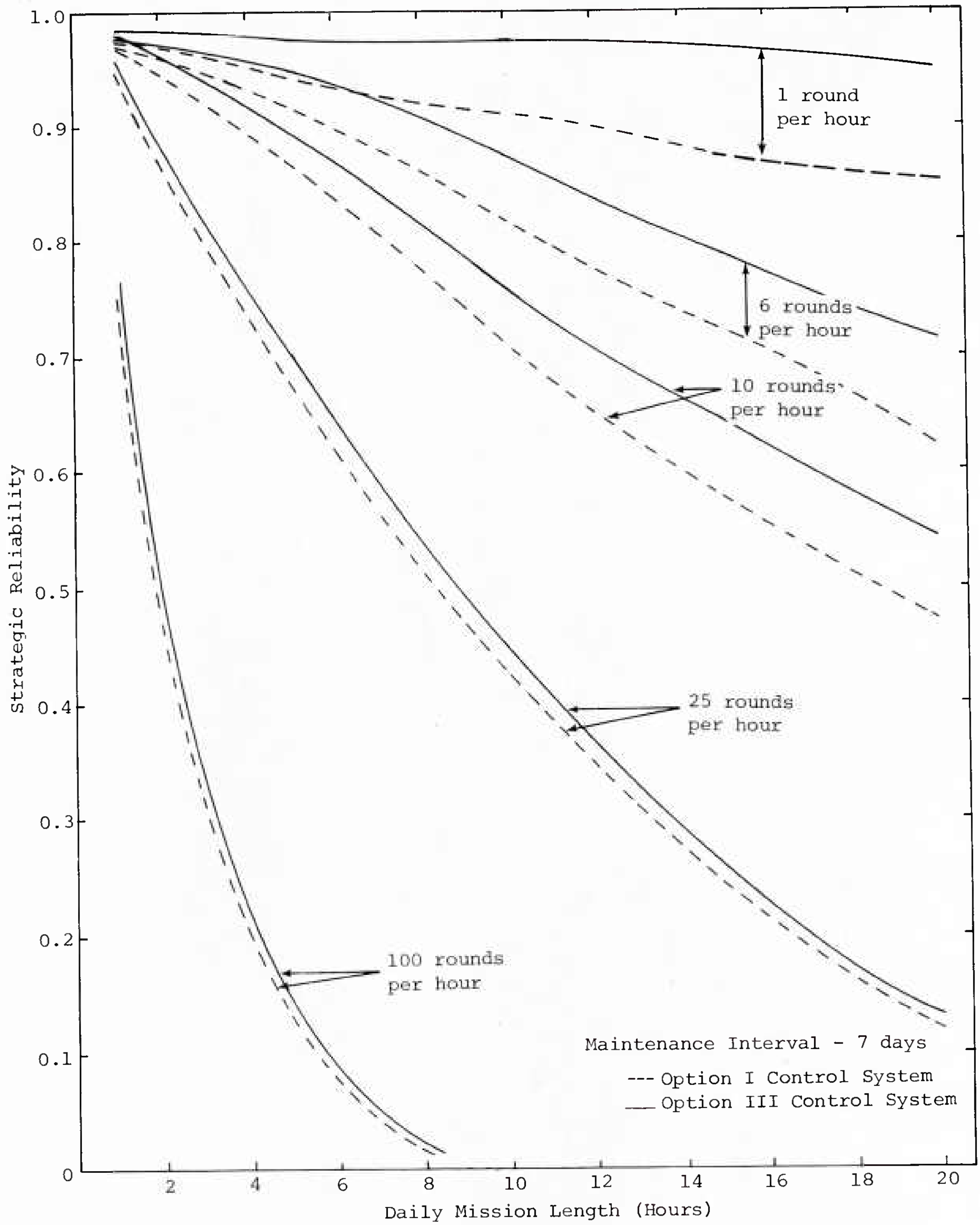

Figure C-6. MK 71 MOD 0 STRATEGIC RELIABILITY VERSUS MISSION FOR A SEVEN-DAY PREVENTIVE MAINTENANCE INTERVAL

APPENDIX D

DEVELOPMENT COST ESTIMATE SUMMARIES FOR A TRIPLE-MICROPROCESSOR-BASED STANDARD ELECTRONIC MODULE (SEM) MK 71 MOD 0 GUN MOUNT CONTROL SYSTEM

1. NOSL PROJECTED DEVELOPMENT COSTS

Figure D-1 shows the schedule and projected costs for the development of a microprocessor-based control system for the Mk 71 Mod 0 that were given in GSEC/NOSL Report R228. These costs formed the basis for the microprocessor control system development costs used in this report. Changes made to these costs are detailed in Section 6.1.1.3 of this report and Section 2 below.

2. SOFTWARE DEVELOPMENT COSTS

A complete software package for the triple-microprocessor-based Mk 71 Mod 0 Control System includes two separate sets of control and functional program logic. One set is required for the train and elevation processor and the other set is for the two loading and firing processors, which can operate from essentially identical software. It is estimated that each program logic set will require about 8000 memory words and will include processor-control executive program logic, functional gun mount control program logic, and built-in test (BITE) program logic. The executive and BITE program logic are estimated to require about 2000 memory words with the remaining 6000 words dedicated to the functional mount control program.

Software engineering and software development management topics in the literature distinguish between the complexity of executive and BITE-type programs and functional programs, with functional programs being considered less complex. Productivity estimates for software development that have been empirically derived from development histories indicate that executive-program-type logic is produced at a rate of 600 words per man-year, and functional program logic is produced at a rate of 6000 words per man-year. Using this information, an estimated cost for computer software for the Mk 71 Mod 0 microprocessor-based control system was derived as shown in Table D-1.

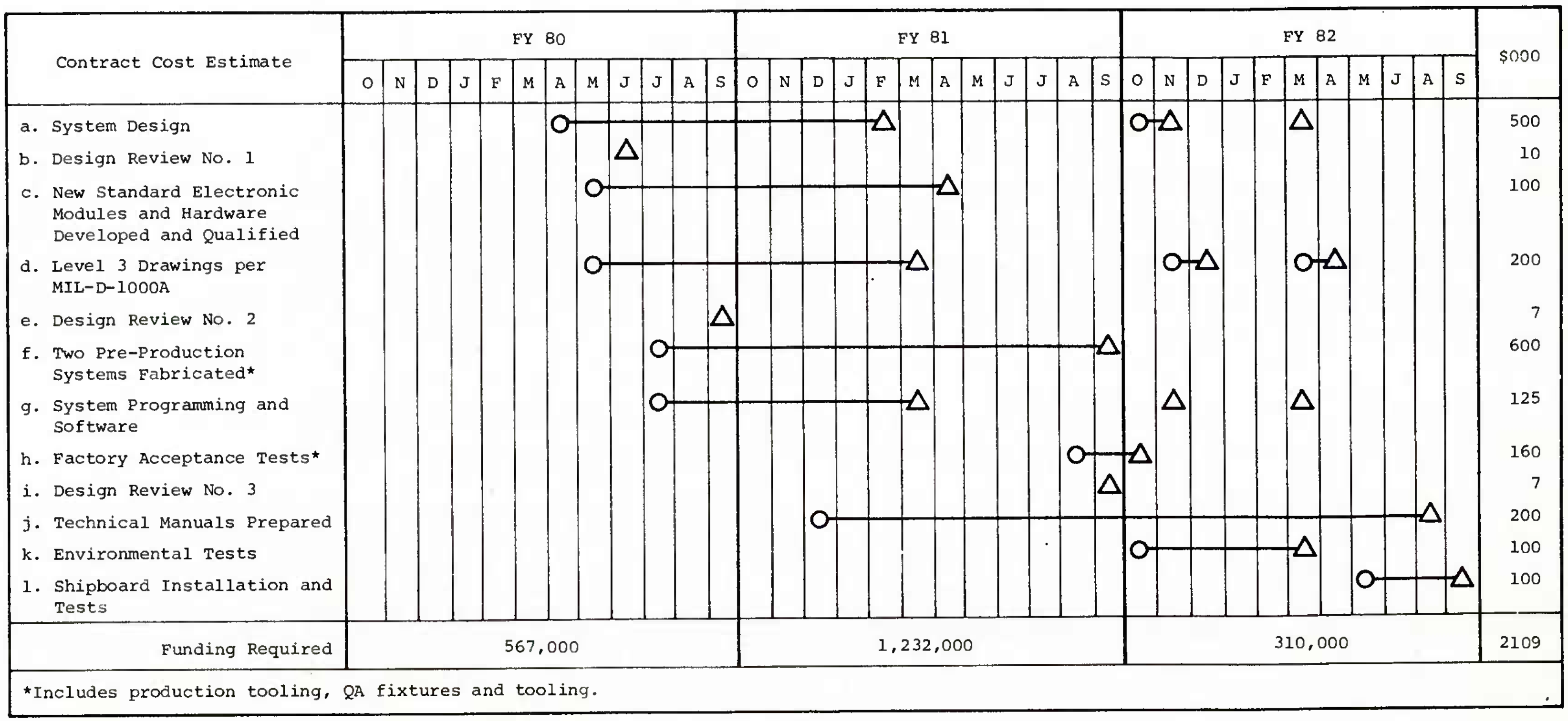

Figure D-1. PROJECTED DEVELOPMENT SCHEDULE AND COSTS FOR MICROPROCESSOR-BASED CONTROL SYSTEM

Table D-1. PROJECTED SOFTWARE DEVELOPMENT COSTS

Train and Elevation Processor Software

$$2000 \text{ executive program words} \div \frac{600 \text{ executive program words}}{\text{man-year}} = 3.3 \text{ man-years}$$

$$6000 \text{ functional program words} \div \frac{6000 \text{ functional program words}}{\text{man-year}} = 1.0 \text{ man-year}$$

Loading and Firing Processor Software

Executive program development effort = One-third T&E executive program = 1.1 man-years

Functional program development effort = T&E functional program requirement = 1.0 man-year

Software Documentation

General Description Documentation	-	1 man-month	
System Program Documentation	-	4 man-months	
Software Training Documentation	-	1 man-month	
		6 man-months	= 0.5 man-year
Software Development Management			1.0 man-year
		Total	7.9 man-years

$$7.9 \text{ man-years} \times \frac{\$50{,}000}{\text{man-year}} = \$395{,}000$$

Computer usage/software development system = 50,000

Total $445,000